ИЗВЕСТИЯ
АКАДЕМИИ НАУК СССР
СЕРИЯ ГЕОЛОГИЧЕСКАЯ

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A TECTONIC CLASSIFICATION OF SAKHALIN

by

A. V. Solov'yev

The author disputes the validity of opinions expressed by S. N. Alekseychik and K. I. Gnedin, consider the structure of the entire Sakhalin area during Tertiary time as a foreland dis-t adjacent to a geosynclinal trough east of the present island. Three tectonic zones on the nd are identified by the writer, based on studies and analyses of folding in many locations Sakhalin. These represent geosynclinal, intermediate, and platform provinces present dur- Tertiary time.

* * * * *

nterpretations on the tectonic structure of halin which have been published to date, 6], are based on three main geomorpho-c features of the island. These are two rply-defined ridges and the valley which arates them, extending from Anivsk Bay he south to Baykal Bay in the north.

'e. M. Smekhov and S. N. Alekseychik ard these three elements as three geo-onic zones. They are the western Sakhalin clinoria and the central depression, erred to also as the central synclinorium), ch separates them.

Details vary somewhat in the two studies. projects, however, as well as a series unpublished studies of the region, were ier unfortunately carried out with only rse attention given to such important con-erations as the tectonic development of region, the nature of tectonic activity nin individual structural zones, the mor-logy of existing folds, and geophysical a obtained from surveys of the region. l use of such material would permit an quate understanding of the more profound nplexities of the structure of Sakhalin.

An attempt of any magnitude, however, interpret Tertiary aspects of Sakhalin in trast to the present can introduce some blems. The folding on Sakhalin has been ught to be of the platform type. V. V. ousov characterizes the platform type folding as typically comprised of gentle chifolds which tend to exist as isolated uctures, each having individual charac-istics.

Using these criteria as a basis, S. N. kseychik [2] considers all of Sakhalin an ermediate region between the platform l the geosyncline, "which was centered east of the present boundaries of the island." Gravimetric and magnetic surveys conducted in Northern Sakhalin were assumed by K. I. Gnedin to support his terming the western portion of the island a platform district and the eastern an intermediate region between the platform and the geosyncline. Tatar Strait originated, in his opinion, from erosive action, followed by a gradual subsidence of the area during Tertiary time.

These views may be true and valid as supporting evidence only when they are restructed to specific areas where actual studies have been conducted and specific types of structures have been identified. In the northeastern portion of the island, for example, gravimetric surveys have obtained local indications of elongation of maximum and minimum readings. In the western part of the northern half of the island, gravity zones also have an elongated orientation.

Magnetic surveys in the northern half of the island produced similar results. In eastern Sakhalin, divergence is low (up to 80 gammas), whereas in the western part of the island, large variations in magnetic intensity occur.

Since no gravimetric or magnetic data is available for southern Sakhalin, a projection of the results obtained in the northern part of the island into the unstudied remainder of the island, as attempted by K. I. Gnedin, can be considered rather venturesome and open to question.

The geosynclinal district, as distinct from the platform, is characterized by the greatest tectonic diversity [1]. This is expressed by closely spaced zones of upwarp and downwarp, a wide vertical range of positive and negative tectonism, and relatively complex

disturbances affecting sedimentary deposits in the geosyncline.

V.V. Belousov further characterizes folding of the geosynclinal district as "full" or linear, i.e., folds occurring in uninterrupted linear sequences occupying the entire area of the geosyncline.

Platform districts on the other hand, have localized, isolated folding affecting horizontally-lying strata. Platform folding lacks the uninterrupted linear sequence of structures typical of the geosynclinal district. Folded platform strata retain their horizontal orientation.

Folding in Sakhalin was found to be of the platform or intermediate type, with certain districts exhibiting the "full" or linear folding typical of the geosynclinal district, at the Western Sakhalin Ridge and its western foreland along the west coast of the northern part of the island.

The Western Sakhalin Ridge is a complex anticlinorium, the tectonics of which are still not entirely clear at the present time. Its complexity suggests however, that this tectonic element of Sakhalin cannot be classed as a platform type. Neither is it possible to class the region as one of intermediate type of folding. It is impossible to draw a parallel between the tectonics of the Western Sakhalin Ridge and the frontal slopes of the Caucasus geosynclinal district, where V.V. Belousov delineated a geosynclinal to intermediate type of folding, i.e., the comb ridge folding. Such a classification is logical because linear sequence in structures of the Western Sakhalin anticlinorium is sharp, uninterrupted and easily discernible, a condition not present in the foreland ridges of the Caucasus. Folding in the western Sakhalin anticlinorium, affecting calcareous rocks, must consequently be classed as the "full" or linear type, characteristic of geosynclinal districts in the concluding stages of their development.

The Western Sakhalin Ridge is bordered on the west and east by two tectonic depressions, or synclinoria. These are easily discernible, because of the monoclinal dip and good exposures of units in the western part of the island ranging from older to younger westward. In the eastern part of the island, progression of strata from older to younger occurs eastward.

This is in accord with K.I. Gnedin, who concluded that the Tatar Strait originated as a result of erosion rather than of tectonic activity. A river channel was apparently cut through the district during the Eocene epoch, as judged by changes in thickness and lithology of Tertiary outcrops from east to west along the western coast of southern Sakhalin.

This district, the western foreland of the Western Sakhalin Ridge, has characteristic linear folding. The trend of fold axes here parallel those of the Nizhneduysk and Khandasinsk suites of the Paleogene and Lower Miocene, (Fig. 1). Horizontal strata, with the exception of axial segments of anticlinal and synclinal folds, are not present in the area.

With careful examination of the morphology of these structures, a west trend is evident in the region. Western flanks of folds dip at steeper angles than do the eastern. Other studies and reports have also made note of the steeper western limbs of anticlinal structures in the region.

With consideration of all of these factors, we can consequently and assuredly apply the terminology introduced by V.V. Belousov, and designate the district as one of the "full" or linear type of folding.

This permits the assumption that western Sakhalin, the western foreland of southern Sakhalin, and very probably also the Tatar Strait district are non-platform types. Since the evidence mentioned has already excluded the classing of the district as an intermediate region, as K.I. Gnedin was inclined to do, the region must necessarily be considered a geosynclinal province during the Tertiary period.

Only a small part of Sakhalin, the northwest of the island, is a platform region. This is an area of gentle discontinuous folding. Gravimetric and magnetic data emphasizes its distinctive character and sharp contrast with the remainder of Sakhalin.

Attempts at outlining the nature of folding east of the Western Sakhalin Ridge, including the Susuya and Nayba River valleys as well as the western shorelines of the Okhotsk Sea and the Terpeniya Gulf, have encountered some difficulties.

S.N. Alekseychik referred to the central depression as the central Sakhalin synclinorium and noted its thick cover of Quaternary deposits. In the western range, Tertiary deposits unconformably overlie Paleozoic rocks along the east bank of the Nayba River.

Geological surveys in the southern portion of the central synclinorium have uncovered several anticlinal structures, two of which, the Dolinsk and the Aynsk anticlines, may be in a linear relationship. However, the clear linearity characteristic for the "full"

folding cannot be delineated. Other structures in the area such as the Korsakov or Magun-can, are gently-sloping, isolated, brachianti-clinal folds, characteristic of the interrupted type of folding. Another feature of this area which includes the Susuya and Nayba River valleys, is the absence of volcanic rocks, volcanic facies of Tertiary deposits, and other phenomena associated with volcanism, thus emphasizing the different nature of this district from the Tatar Strait synclinoria.

Folded structures of northeastern Sakhalin, in which important oil-bearing rock units exist, commonly underwent sharp changes in lithology during relatively short periods of geologic time. Geological surveys and oil drilling operations have outlined many anti-clinal folds which show tremendous morpho-logic variations.

N.P. Budnikov and some years later, K.I. Gnedin attempted a classification of these diverse anticlinal structures on the basis of their morphologic characteristics. N.P. Bud-nikov's classifications included an entire series of types. K.I. Gnedin suggested a simpler classification in only three morpho-logic classes.

Such classification is commendable, but it must be kept in mind that diversity of anti-clinal structures of northeastern Sakhalin exists not only in morphology but also be-cause of other differentiating elements, such as varied directions of axial trend. Folds with steeper and in places overlapped eastern limbs occur in Ekhabi and Eastern Ekhabi, but in the Paromay and Gyrgylan'i districts, folds have steeper western limbs.

Previous interpretations of geologic explora-tion on Sakhalin cite four directions of strike of anticlinal structures on the island. The easternmost of these was believed to parallel the coast along the Okhotsk Sea. Subsequent investigations, however, have indicated the unrelated and random arrangement of individ-ual structures.

All of this serves as the basis for assum-ing that this area is one of intermediate type of folding. Graben and box structures in the area are numerous. The Eastern Ekhabi graben and the Katangliysk and the Nutovsk box structures are particularly interesting.

Late Tertiary folding on the Shmidt Peninsula is rather difficult to interpret. It was suggested that during the second half of the Tertiary Period, this district had already acquired the character of an inter-mediate district, i.e., one occurring between the geosyncline and the platform. However, the numerous early Tertiary extrusives and inverted folds tend to support the probability that the area was a geosynclinal district during Early Tertiary time.

It is apparent from our study and discus-sion of the nature of folds, the lithology, the tectonic zoning and the tectonic scheme (Fig. 2) of Sakhalin, that the district can be interpreted in a somewhat different light than than assumed by earlier studies of Ya. M. Smekhov and S. N. Alekseychik.

The region of "full" folding comprises the western Sakhalin Ridge which is an intrage-anticline that evolved during Middle Miocene

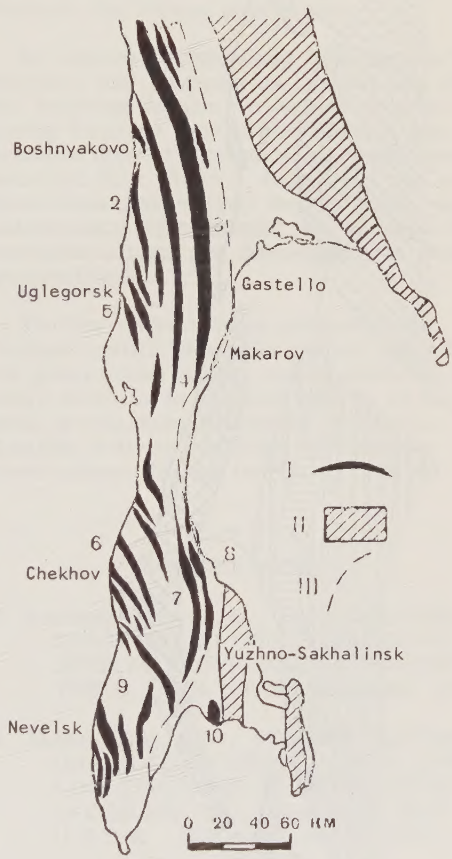

FIGURE 1. Character of folding in the Tatar Strait geosynclinal district

I -- Anticlinal folds; II -- Older consoli-dated areas; III -- presumed boundary of the Cenozoic geosynclinal district.

1 -- The Khandasinsk group of folds; 2 -- Lesogorsk-Boshnyakovo group of folds; 3 -- the Poronaysk Ridge Anticlinorium; 4 -- The Primor-skiy Ridge anticlinorium; 5 -- Uglegorsk group of folds; 6 -- Chekhov group of folds; 7 -- South-Sakhalin Ridge anticlinorium; 8 -- Aysk group of folds; 9 -- Nevelsk group of folds; 10 -- Korsakov structure

time as a result of the separation of the Tatar Strait geosyncline into intrageanticlinal and intrageosynclinal members. The intrageosynclinal district was comprised of what is now the eastern part of the Tatar Strait and the western coast of Sakhalin.

The southern part of the central Sakhalin depression, together with the greater part of northern Sakhalin is classed as an intermediate district, occurring between the consolidated platform and the geosyncline. The western coast of the northern part of the island is apparently a platform district which was already well consolidated at the beginning of Tertiary time.

The part of the island overlain by Paleozoic rocks must also be regarded as having been a well-consolidated platform district during Tertiary time. Paleozoic rocks outcrop in the

FIGURE 2. Tectonic scheme for Sakhalin for the second half of the Tertiary Period

1 -- Platform district; 2 -- intermediate district between platform and the geosyncline; 3 -- consolidated older folds; 4 -- western Sakhalin intrageanticline; 5 -- Tatar Strait geosynclinal district; 6 -- Khandasinsk zone; 7 -- Dudinsk zone.

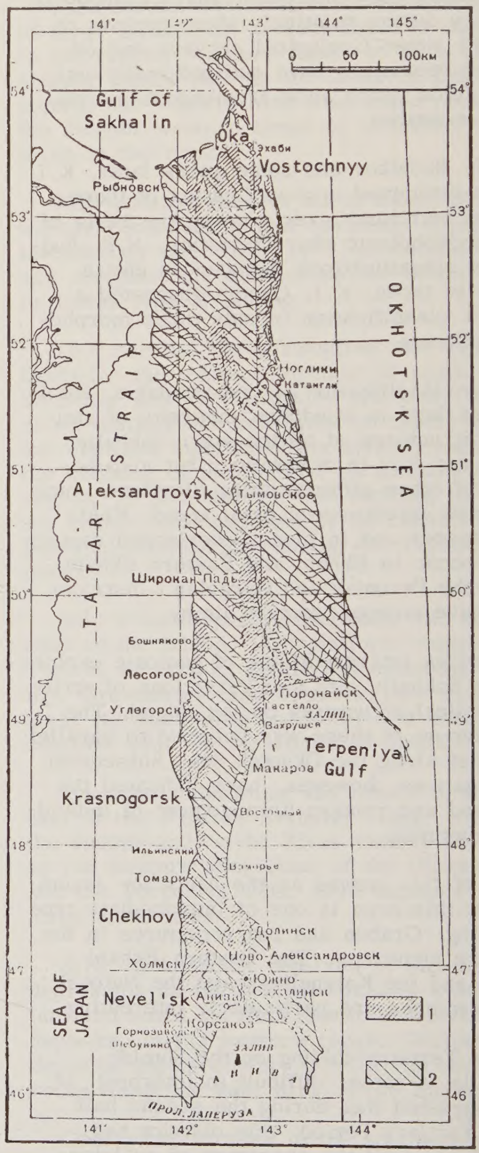

FIGURE 3. Distribution of mobile zones in the Tertiary history of Sakhalin

1 -- Mobile zones; 2 -- Consolidated regions

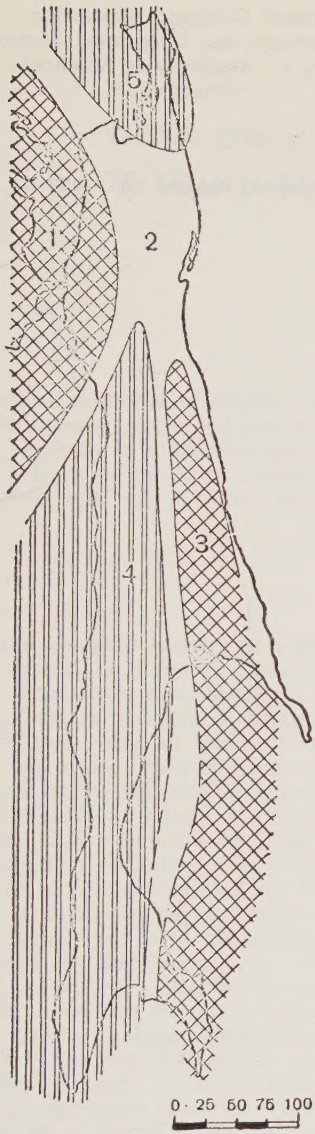

FIGURE 4. Structuro-tectonic plan of Sakhalin for the first half of the Tertiary Period

1 -- Platform district; 2 -- intermediate one; 3 -- consolidated older folds; 4 -- Tatar trait geosynclinal district; 5 -- Shmidt Pennsula geosyncline.

astern Sakhalin and the Susunaysk Ridges which are Paleozoic massifs of the Tonino-Anivsk Peninsula.

Geophysical data, lithologic studies, and analysis of thickness of individual stratigraphic units establish within these tectonic zones, (which include the geosynclinal district itself as well as the intermediate district) a sevenfold zone of subsidence active through Tertiary time on Sakhalin (Fig. 3).

During the first half of the Tertiary Period, such a sevenfold differentiation had not bet developed (Fig. 4). The entire district including the Tatar Strait, the western shore of the southern part of Sakhalin, the Western Sakhalin Ridge and possibly even part of the central Sakhalin depression were, at that time, part of one geosynclinal trough, bounded on the west by the western Asiatic platform and on the east by Paleozoic massifs which were subjected to Mesozoic diastrophism. One can surmise that these massifs were geanticlines of a still older and much larger geosynclinal district, the Nippon geosyncline.

In summary, restricting ourselves to the territory that interests us, we can see that the following sequence of stages occurred during Tertiary time in the Sakhalin geosynclinal district: accumulation of sediments occurred first within a widespread and rather featureless geosynclinal district which was subsequently differentiated into upwarps (the intrageanticlines) and downwarps (the intrageosynclines).

Further differentiation occurred with elongate uplifts within the central part of the geosynclinal trough, accompanied by a sharp increase in volcanic activity at the time of maximum subsidence of basins. Tectonic activity concluded with intense diastrophism through the entire district.

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DATA ON MIDDLE MIOCENE VOLCANISM OF SOUTH SAKHALIN (CHEKHOV DISTRICT)

by

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One typical example of Middle Miocene volcanism on southern Sakhalin is examined in this study. Occurrence, lithology and thickness of volcanic deposits, (the Chekhov suite), are described. Changes in thickness and lithology of volcanic rocks are outlined. An analysis of volcanic activity in the area shows that the Chekhov suite deposits are not an independent stratigraphic unit, but are the volcanic facies of the Nevel'sk suite.

* * * * *

Repeated volcanic activity in southern Sakhalin during the Tertiary period has resulted in sidespread distribution in Tertiary deposits of rocks of volcanic origin. Among these, volcanic rocks of Middle Miocene age are very important. Volcanic activity within the district during the Middle Miocene was somewhat localized. Resulting deposits consequently occur in a small area (Fig. 1). The Chekhov district on Sakhalin is a typical example of local volcanism of the Middle Miocene. This is the region where such volcanic rocks were first considered independent stratigraphic units, i.e., the Chekhov suite. Moreover, Middle Miocene deposits have been correlated with and defined as members of the Chekhov suite on the east coast of the southern half of the island, in the Makarov district. In the Krasnogorsk district, also, equivalent deposits comprise the upper part of a volcanic complex which so far has not been described definitively. This is known as the Khoyndzho suite, but is also commonly referred to as the Chekhov suite.

It has been theorized that Middle Miocene volcanic deposits on Sakhalin do not comprise an independent stratigraphic sequence because of their localized distribution and distinctive lithology, as noted in field investigations, one of which was conducted by Ye. M. Smekhov, [4]. More recent studies, (by S.N. Alekseychik and others, [1], and stratigraphic cross-sections prepared by geologists of the All-Union Scientific Research Institute for Geologic Exploration (VNIGRI), indicate that deposits referred to as the Chekhov suite are not be be considered equivalent in complexity to other known sequences in the Teritary section of Sakhalin.

In the Chekhov district, Middle Miocene volcanic rocks underlie and are included within the Nevel'sk suite as well as in deposits of the Uglegorsk suite which overlies the Nevel'sk. Moreover, the entire complex of folded and faulted Tertiary deposits on Sakhalin has volcanic interbeds in contact with normal sedimentary deposits of various ages.

A great many types of coarse-grained sediments have been assigned to the Chekhov suite, (e.g., breccia, conglomerate, coarse-grained sandstone and other rock types). The main constituents in all of these are materials of volcanic origin. The volcanic constituents occur as angular, sub-angular or rounded aggregates of basalt and porphyrites ranging from extremely small fragments, a fraction of a millimeter in sandstone and arenaceous siltstone, up to fragments 2 millimeters in diameter in coarse breccia. Volcanic material, furthermore, comprises a major part of the cementing material which has formed the matrix between these fragments of pyroclastic rocks.

We must note that these rocks are referred to as volcanics, since volcanic material is predominant in their composition. We should not confuse them, however, with pyroclastic rocks in situ, which contain a predominant amount of material of volcanic origin. Pyroclastic rocks in situ, such as various tuffs, are considerably more rare and thinner within the Chekhov suite than are the redeposited fragmental volcanic formations.

The thickness and lithology of the Chekhov suite on Sakhalin are not uniform. Geologic

mapping has revealed that the greatest thickness (1,125 meters) of the Chekhov suite occurs in the district between the Chekhov and Arkanzas Rivers (Fig. 2). Rocks of the Chekhov suite here, are coarse and fragmental.

Well-exposed rocks of the Chekhov suite occur at the sea coast, 0.5 to 2.0 kilometers north of the estuary of the Rudanovsk River. Large exposures of the section here contain light-gray, coarse-grained sandstone which contains well-rounded pebbles of volcanic rock. These are 3 to 4 centimeters in diameter. The light-gray sandstone alternates with greenish dark-gray, medium-grained sandstone which also contains redeposited volcanic material. In each of these sandstones, volcanic material predominates. Upwards from the base of the outcrops, the diameter of volcanic clastic fragments tends to increase to rather remarkable dimensions - up to 15 centimeters with some attaining diameters as great as 1.5 meters. The majority of these aggregates have high sphericity and are well-rounded, particularly those of medium size. These volcanic rocks are primarily dark gray with somewhat lesser amounts of brownish and even reddish basalt and basaltic porphyrite.

Large volcanic aggregates occurring in these fragmental volcanic sediments are commonly 50 percent of the total. Silica, along with fine volcanic rock fragments, serves as the cementing material.

It has been noted, from the sections of outcrops in the district that breccia predominates, but since most aggregates are well-rounded, it is more suitable to refer to these sections as conglomerate breccias.

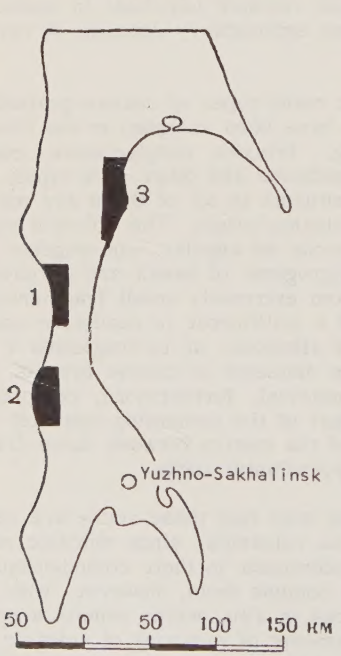

FIGURE 1. Locales of Middle Miocene volcanism in southern Sakhalin

1 -- Krasnogorsk district; 2 -- Chekhov district; 3 -- Makarov district

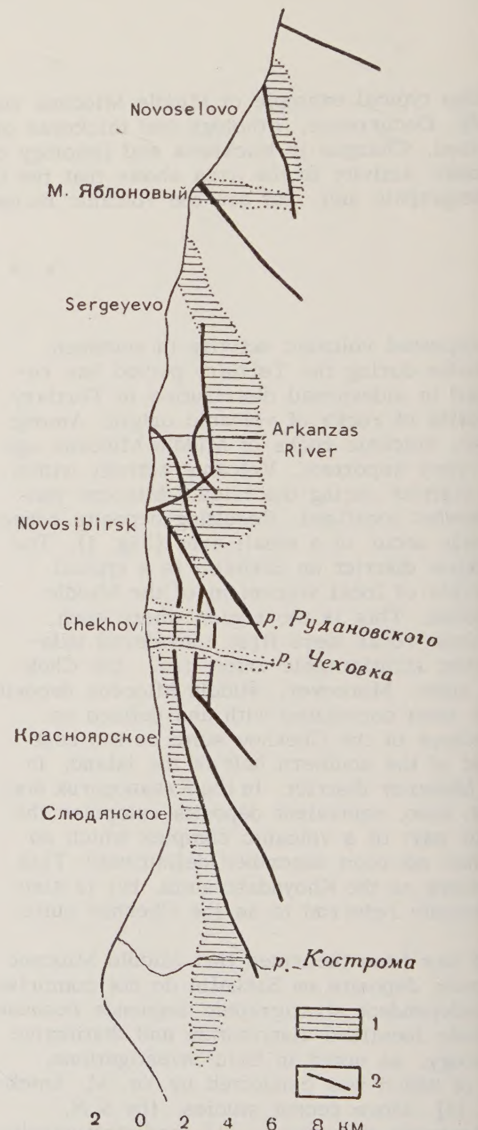

FIGURE 2. Distribution of Middle Miocene volcanic deposits in the Chekhov district of south Sakhalin

1 -- Middle Miocene volcanic deposits; 2 -- faults.

Aggregate thickness of the accumulations is many meters at the shoreline.

Good exposures of the Chekhov suite occur along the Arkanzas River, nine kilometers north of the first location mentioned; somewhat coarser material predominates in this 1,000-meter section. Basal members of the section consist of a matrix of dark green and gray, coarse-grained sandstone which contain well-rounded pebbles and somewhat smaller percentages of angular fragmental material. These coarse inclusions within the sandstone matrix are predominantly pebbles and fragments of basalt and porphyries. Overlying strata have increasingly greater percentages of coarse inclusions.

Size of the individual inclusions also increases concurrently with the upward increase in percentage of coarse material. Near the bottom of the section, coarse materials average 30 to 40 centimeters in their maximum diameters, but increase rapidly to an average of 1 meter at the center of the vertical section.

Roundness of coarse material tends to decrease somewhat from bottom to top. Coarse-fragmental breccia occurs at the top of the section. It is comprised of elongated, angular fragments of volcanic rocks. Groundmass material, introduced into the interstices between the larger fragments, consists of smaller fragments of volcanic rocks. The cement is a siliceous material of volcanic origin, and has a greenish, dark gray color.

The coarse, fragmental constituents of the top members of the suite attain a maximum thickness of 2 meters.

Throughout the Arkanzas River section, rocks comprising the Chekhov suite are coarse conglomerate breccias and fragmental breccias which contain volcanic fragments of tremendous size. The largest boulders in the top members are 2 meters in diameter. These large inclusions, as well as the ground-mass and cementing material are predominantly of volcanic origin.

Thickness of the Chekhov suite diminishes rapidly to the south. Between the Chekhov and Krasnoyarka Rivers a thickness of only about 500 meters has been noted.

Lithology of the suite in this area differs greatly from that observed at exposures of the suite at the Arkanzas River. One notable difference is the smaller percentage of very coarse, volcanic fragmental material present in the district.

Tuffaceous gravel, sandstone and shale predominate in the area. Chekhov suite conglomerate breccias on the lower reaches of the Chekhov River are several tens of meters thick. Volcanic rock inclusions, however, have smaller diameters and higher roundness than at more northerly locations. Widely-distributed conglomerates occur in the district. Thin constituents are mainly of volcanic origin. Isolated lenses of tuffaceous sandstone occur at intervals within the conglomerate sequence. Sheet sandstone with identical lithology is also widely distributed at this location.

Immediately north of the Krasnoyarka River, conglomerate breccias of the Chekhov suite are only several meters thick.

Inclusions of large size are rare. Those present are 0.4 to 0.5 meters in diameter. Small-pebble conglomerate and coarse-grained sandstone are the prevailing rocks in the district.

Percentages of well-rounded inclusions of redeposited extrusives are higher. Occasional siltstone laminae and strata are interbedded with the prevailing conglomerate breccias. A widespread siltstone sheet is as much as 40 centimeters thick at the mouth of the Krasnoyarka River. Occasional semi-rounded fragments of rocks of pyroclastic origin are present within this thin siltstone layer. They do not, however, form independent layers of much significance at any point within the district.

The villages of Kostromskoye and Pionery lie south of the Krasnoyarka River. Core sampling and field mapping conducted between the two settlements indicate the thickness of the Chekhov suite in the northern part of the map area to be an even 500 meters. Thickness diminishes rapidly to the south, to about 4 or 5 kilometers south of the Kostroma River, where the Chekhov suite passes gradationally into deposits of the Nevel'sk suite. Layers of conglomerate breccias and coarse fragmental conglomerates occur not very far from the village of Krasnoyarskoye. They consist of semi-rounded cobbles and boulders of volcanic rocks with diameters up to 10 centimeters. These are interbedded with volcanic tuff, siltstone and sandstone. These rocks contain small, well-rounded pebbles of extrusive rocks, which are not generally greater than 6 centimeters in diameter. The sandstone at some points increases in percentage of contained pebbles thus grading upward into conglomerate. However, these sandstones are not widely distributed in this area.

Consequently in part of the Chekhov suite south of the Arkanzas River, in a distance of 28 to 29 kilometers, the thickness drops

from 1,125 meters to nothing. A gradual change in lithology accompanies this change in thickness. Coarse fragmental volcanic breccia, conglomerate breccia and conglomerate, occur in the thicker parts, followed by gravel, sandstone, and siltstone comprised mainly of volcanic material. The widely-disseminated pebbles of extrusive rocks rarely form thin layers and lenses of an all-pebble conglomerate. Besides these volcanic fragmental and normal sedimentary deposits, materials in situ, such as psaphitic and psammitic tuff and tuffite are increasingly abundant.

Thickness of the Chekhov suite also diminishes north of the Arkanzas River. Geologic mapping in the district from Sergeyevo northward to Novoselovo shows a thickness ranging between 400 and 1,000 meters. Visible thickness of the Chekhov suite at Novoselovo is not great. By analogy with the measured thickness to the south, the total thickness at Novoselovo is believed to be 1,000 meters.

Variation in thickness of the suite occurs to the north as it does south of the Arkanzas River. Immediately north of the Arkanzas River, coarse fragmental volcanic formations such as conglomerate breccias are prominently distributed. However, near the village of Sergeyevo, coarse-grained sandstone comprised mainly of volcanic material occurs in thick beds. Sandstone and siltstone with high percentages of normal sedimentary material and volcanic tuff in situ are also well represented. Most of the coarse rocks here are conglomerate comprised of well-rounded, medium-sized basaltic pebbles. The maximum size of included pebbles is 5 centimeters. Isolated semi-rounded cobbles with a breadth of about 10 centimeters occur rarely.

North of the village of Sergeyevo, coarse volcanic formations again are significant. Breccia occur again on Cape Yablonovyy. These contain angular and, in places, semi-rounded inclusions of extrusive rocks. Average size of these is 15 to 20 cm with maximum size 1.0 meter. Matrix and cement are largely psammitic tuff, which occurs also in the area as independent beds with a thickness up to 3 meters.

Essentially analogous to its distribution south of the Arkanzas River, the Chekhov suite passes gradually into the underlying Nevel'sk suite 1 kilometer north of the village of Novoselovo.

At a short distance inland along the Taemi River (right tributary of the Novoselka), the Chekhov suite, is represented largely by volcanic tuff, which comprises the major portion of the section here.

North of these areas deposits of the Chekhov suite do not occur, and are replaced by normal sedimentary deposits and by sporadic volcanic deposits of the Nevel'sk suite.

It has been readily affirmed that even a cursory view of deposits of the Chekhov suite shows that changes in lithology accompany change in thickness of the suite. Individual local conditions affecting formations are largely responsible for this variation as we shall see below.

Distribution of the rather scarce but characteristic marine fossil fauna within the Chekhov suite is also dependent on local conditions. These fossils include Mytilus tichonovitchi Mak., M. chejslevemensis Slod., Ostrea kovatschensis Slod., Pecten lautus Gould, Thyasirs bisecta (Conrad) var. alta L. Krisht. Such a fauna confirms the Middle Miocene dating of these deposits.

At several locations along the coast, (at the village of Novoselovo, at Cape Yablonovyy and in the Rybnitsa and the Arkanzas River valleys) Chekhov suite deposits include sheeted magmatic injections, which generally do not exceed several meters in thickness. Thicker sections are occasionally present, but are very rare.

These magmatic injections, judged by their intrusive contacts with the country rock, and their characteristic hypabyssal textures, are mainly dolerite dikes and sills. A few of the magmatic masses are lithologically similar to extrusive rocks, and have unclear relationships with the country rock; these rocks can be considered as remnants of large subvolcanic flows or, possibly, of basaltic blankets. The magmatic masses occur in those regions in which volcanic deposits have the greatest thickness and coarseness.

Inclusions of volcanic rocks in breccias, conglomerate breccia, conglomerate and other coarse-grained formations are largely redistributed olivine or non-olivine basalts and their porphyries; there are some inclusions, however, whose composition approaches that of spillite. Rocks of the intrusive masses are younger than the basalts but have identical mineralogy, and differ from them only in texture. A short resume of the mineralogic and chemical composition of these and other rocks has been published [5].

Thickness and lithology of the Chekhov suite as outlined above confirm earlier studies which indicated that during Middle Miocene time, there existed two independent centers of volcanic action in the district. One of these was located on the Chekhov River, near the mouth of the Arkanzas River.

'his has been termed the Chekhov center.

The second center of volcanic action was amed the Novoselovo center after its loca- on approximately at the village of Novo- elovo.

West of these areas, core samples have iown that recent subsidence and marine ansgressions have made the exact charting adjoining centers rather difficult. How- ver, by consideration of lithology of the eposits and dimensions of contained volcanic clusions, one can surmise that the bound- y of the Novoselovo center was not more an several kilometers west of the marginal itcrops of the Chekhov suite along the shore the Tatar Strait. The western boundary of e Chekhov center was approximately the me distance from the shore as that of the ovoselovo center or perhaps even closer the present coast of the island. Confir- ation of these views is difficult, because ese remnants of volcanic centers, as entioned previously, are inaccessible.

At the present time, the conditions of velopment and type of volcanic activity curring during Middle Miocene time can merely surmised. Products of this activ- y, its resultant volcanic deposits, furnish clue to its nature and development.

The conformable accumulation of volcanic posits atop the normal marine sedimentary posits of the Nevel'sk suite, the reworked agmentary material in near-shore regions, d the remains of marine organisms gives idence that a marine environment existed ior to the beginning of volcanic activity d continued during its development.

Regions of great eruption and immense cumulation of volcanic material built up otuberances which formed small, individual lands above the surface of the sea. On any of these islands there are indications at a large percentage of volcanic rock clusions had a subareal origin. These were deposited in coarse fragmentary form. emains of a terrestrial flora - ancient tree unks in this case - are widely distributed these rocks; imprints of fresh-water fish e also present.

Areas which were nearest to the volcanic nters have heaviest accumulations of coarse agmentary material, such as breccia and nglomerate breccia, mainly comprised of lcanic material. A number of petroleum ologists hold the opinion that these are roclastic materials in situ. Inclusions of rphyritic basalts within them are believed be volcanic bombs [3]. These inclusions ve a characteristic spindle shape and a rface texture reminiscent of a bread crust or of a cauliflower. Gas blisters are common in their internal structure. These decrease in size and number progressively from the center to the surface. Their luster is either dense or vitreous. However, volcanic inclu- sions within the Chekhov suite breccia and conglomerate breccia cannot be considered as volcanic bombs in situ even though their form or internal structure indicates this. With increasing distances from the center of eruption, these pyroclastics lose their angu- larity, and a progressive change to well- rounded cobbles and pebbles of the same composition occurs within the same strati- graphic layer.

Similar strata, referred to as tuff-breccia and tuffaceous conglomerate are known in Iceland [7], northern California [6], on the Kamchatka Peninsula [3], in the Caucasus [2] and in other areas.

The majority of studies express the opinion that accumulation of such material is associated with activity of glacial melt- water and streams, arising from the thawing or very rapid wasting of a mass of ice or snow in individual glaciers on the summits and slopes of volcanic mountains. Seasonal temperature increases could have brought about the thawing (as in northern California). In Iceland, such thawing has been attributed to volcanic activity. In the Caucasus some redeposition of volcanic material has been attributed to the activity of glacial meltwater streams. However, the leading role in re- deposition is here considered to be a pro- gressive accumulation of coarse fragmentary material (mixed with volcanic ash) on the slopes of volcanic mountains and its subse- quent downcreep down the slopes.

On Sakhalin, breccia and similar coarse fragmentary volcanic accumulations have been largely deposited by glacial streams as the result of seasonal temperature rises, and with more gradual climatic changes. Down- creep of material down slopes is also con- sidered to have been significant. All of these factors, however, were important only in the initial stages of accumulation of these depos- its, prior to their maximum distribution.

Subsequent to the emergence of islands of volcanic extrusives in marine waters, down- slope creep of material as well as stream action brought about an admixture of volcanic material with material of normal sedimentary origin.

The greatly reworked and redistributed volcanic material which at the present time comprises the Chekhov suite is the result of the geologic activities of the sea. This ade- quately explains occurrences of breccia containing large, rounded boulders and

cobbles of volcanic rock, in areas of heavy concentration of volcanic extrusives and their gradual transition into sedimentary breccia, conglomerate, gravel, and coarse-grained sandstone, at increasing distances from these volcanic suites.

The ubiquitous distribution of pyroclastic material in the Chekhov suite is attributed to this same marine activity.

Independent occurrences of tuff in situ are absent in many areas which were in close proximity to corresponding suites of volcanic extrusives not because there was no fallout of pyroclastic material in this area, (on the contrary, volcanic fallout was at its maximum here) but because fallout was rapidly redeposited, and incorporated as ground-mass breccia and similar coarse fragmental rocks. Independent layers of tuff do occur in those places where they were not subjected to rapid redistribution but were quickly covered with younger sediments. Such conditions existed at a distance from volcanic centers, and non-redistributed volcanic tuff can be observed in such locales.

Redistribution of volcanic material began at the time of their formation, continued uninterruptedly during the course of volcanic activity and reached its maximum shortly after termination of volcanism when positive movements of the earth's crust brought about the emergence of a large portion of the territory of Sakhalin. After this, volcanic terrain was subjected to vertual peneplanation. Continental lagoon and near-shore marine deposits of the Carboniferous Uglegorsk suite were subsequently laid down on the peneplaned surface.

Extrusive volcanic activity was also accompanied by subsurface magmatic injections which continued after cessation of surficial volcanism. Evidence of such activity exists in dikes and sills of hypabyssal rock present in non-disturbed volcanic rocks of sub-aerial origin. The close similarity in mineralogic and chemical composition of the extrusive and hypabyssal rocks and proximity of the latter to the corresponding suites of eruptives indicates that these rocks originated from the same magmatic source.

Returning again to the problem of the stratigraphic relationship of the Chekhov suite to the total section of the Tertiary deposits of Sakhalin, we should mention that a genetic analysis of a named stratigraphic suite does not fully establish its independent nature in a stratigraphic sense.

Centers of volcanic activity not only defined the distribution of pyroclastic rocks at the time of their original deposition but also had great influence on the nature of subsequent areal redistribution of this material. Distribution of the volcanic suite regar less of definite changes in lithologic composi tion also resulted in systematic changes in thickness.

Correlation of the Chekhov suite with the underlying Nevel'sk suite also does not provide a basis for considering the Chekhov suite an independent stratigraphic unit. In distribution, the Chekhov is equivalent only to the upper half of the Nevel'sk suite. In fact, with the exception of some isolated cases, overall thickness of both suites remains almost constant, and an increase in thickness of the Chekhov suite is accompanie by a concurrent decrease in the Nevel'sk sui and vice vèrsa. This relationship was noted some time ago by G.K. Nevskiy, (see Table

Subsequent studies have somewhat refined the thicknesses of the two suites given in Table I; however, the general character of their relationship remains almost the same. Increase in thickness of the Chekhov suite is accompanied by a decrease in thickness of the Nevel'sk suite (and vice versa) in the ne data. Overall thickness of the two also remains unchanged.

In summary, it is considered that the Chekhov suite should not be considered an independent stratigraphic unit within the Tertiary deposits of Sakhalin. The distinctiv character of its deposits, however, and the nature of their relationship with adjacent suites, form a basis upon which deposits referred to as the Chekhov suite, may be considered the volcanic facies of the upper half of the Nevel'sk suite.

Table 1

Thickness of the Nevel'sk and Chekhov suites

Number	Location	Thickness in meters		
		Nevel'sk suite	Chekhov suite	total thickness
1	Novoselka R. basin	650	300	950
2	Arkanzas	100	1,000	1,100
3	Baykova-Kita	350	600	950
4	Rudanovskogo	1,000	200	1,200
5	Krasnoyarka[1]	—	—	350

[1]Total thickness cannot be fully determined here due to wide development of disjunctive dislocation.

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STRATIGRAPHY OF THE VERKHNEDUYSK SUITE OF THE WESTERN COAST OF SAKHALIN

by

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This paper outlines the results of correlation of the Verkhneduysk formation of the western coast of Sakhalin, on the basis of analysis of cyclic facies.

The upper and lower boundaries of the formation are specified, with five sedimentary cycles distinguished, each characterized by facies and a coal content of its own. Individual sections are correlated by their cycles, by their lithology and index fossil horizons.

* * * * *

The Verkhneduysk formation of the western Sakhalin coast is exposed within several isolated areas, the largest being the Magachi-Agnevo, Boshnyakovo-Krasnogorsk and the Nevel'sk-Shebunino (see Fig. 1). The most important coal deposits occur in the Verkhneduysk formation of these regions.

Much geologic prospecting and development already has been carried out in most of the area. However, recognition and correlation of different sections of this formation have not yet been accomplished everywhere.

This paper outlines the results of application of the cyclic facies analysis method to the study of the Verkhneduysk formation along the western coast of the island.

1. STRATIGRAPHY OF TERTIARY DEPOSITS

According to recent work by S.N. Alekseychik, I.N. Kuzina and I.I. Ratnovskiy [2], the Tertiary system of Sakhalin begins with a basal conglomerate laid down unconformably on Upper Cretaceous beds (see Fig. 2). The age of this continental conglomerate, up to 600 meters thick, is Lower Eocene.

It is conformably overlain by the Nizhneduysk coal formation represented in its lower part by continental deposits; its upper part is formed by 700-850 m thick continental-marine and marine deposits. The age of the formation is estimated to be Upper Eocene to Lower Oligocene. The conglomerate and the Nizhneduysk formation comprise the Nizhneduysk series.

In a number of localities, the Nizhneduysk series is overlain by the Krasnopol'yevsk formation of littoral and marine deposits, about 650 meters thick, and belonging to the Khandasinskiy series.

It is followed by a very characteristic, true marine Khandasinsk formation, up to 1200 meters thick, and of Oligocene or Lower Miocene age. The Khandasinsk series terminates this major cycle of Paleogene sedimentation.

The Khoyndzhinsk series comprises the volcanic Arakaysk, Kholmsk, Nevel'sk and Chekhov formations of the Lower and partly Upper Miocene, having a maximum aggregate thickness of 3,900 meters.

Higher up lies the Verkhneduysk series, represented solely by the Verkhneduysk formation.

Verkhneduysk time (Middle Miocene) was characterized by continental conditions giving way to a low sea coast with a wide development of isolated basins partly connected with the sea. Marine deposits comprise the upper part of the Verkhneduysk formation.

The cessation of coal accumulation coincides with the appearance of the true marine Okobykaysk deposits of the Upper Miocene.

ome 1,700 meters thick, they are a product a new major marine transgression ending e second (Miocene) cycle of sedimentation.

The Tertiary section terminates in the utovsk series. It is predominantly marine its base, changing upward to continental eposits carrying lignite. Aggregate thickess of the Pliocene Nutovsk series reaches 500 meters.

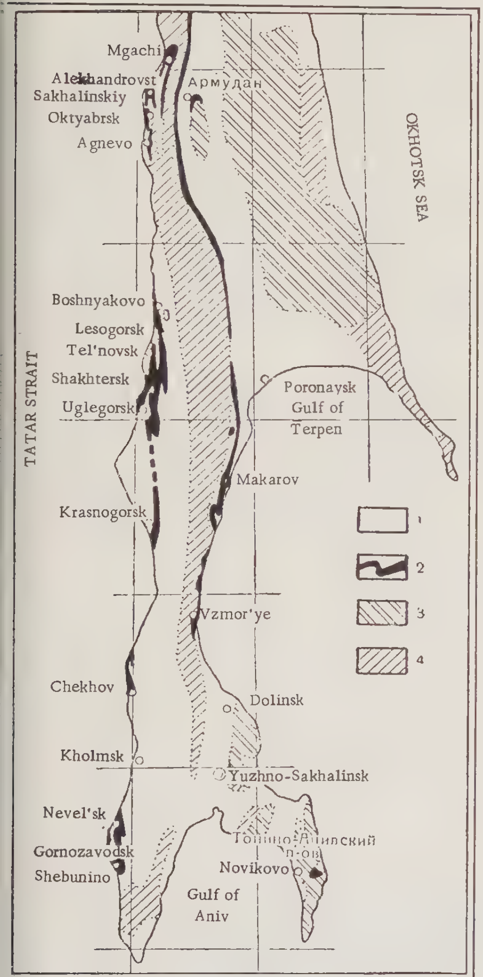

FIGURE 1. Index map of Southern Sakhalin.

1 -- Tertiary deposits; 2 -- Verkhneduysk suite; 3 -- Upper Cretaceous deposits; 4 -- Paleozoic deposits.

The Nutovsk series has initiated a third edimentary cycle which is still continuing.

Thus, the Tertiary of Sakhalin was characterized by three major sedimentary cycles, with the formation of coal measures coinciding with periods of continental stability and the beginning of general submergence. In addition to these major cycles, which may be conveniently called "macrycycles," smaller "megacycles" may be designated as equivalents of stages and sub-stages (such as the Khandasink - Oligocene cycle, the Okobykaysk - Upper Miocene). Within individual series and formations (the Verkhneduysk formation in our case), a cyclicity of two orders is recognized: the "mesocycle" and the "primary" cycle. According to L.N. Botvinkina [3] and A.P. Feofilova [12], the mesocycles are identified by a regular sequence of primary cycles within them.

Unfortunately, the classification of Tertiary deposits of Sakhalin, as proposed by S.N. Alekseychik, I.N. Kuzina and I.I. Ratnovskiy [2], does not include all of the local stratigraphic classifications used in prospecting for coal in various coal fields. For instance, these authors, along with V.D. Kozyrev and I.I. Ratnovskiy [6], give but a single classification for the southern part of the island, that proposed by Ye. M. Smekhov [10]. However, a number of unpublished papers on Sakhalin (A.A. Kapitsa, 1951; A.M. Sayapina, 1950; P.D. Shklyayev, 1949; B.M. Shtempel', 1948), as well as certain works of Japanese geologists such as K. Kavasaki [5] and K. Uvatoko [11], give somewhat different stratigraphic classifications (see Fig. 2).

In order to correlate the results of the lithologic facies study of all individual sections of the Verkhneduysk formation with the results of geologic study along the west coast, it is pertinent to briefly summarize the relationship of this formation to the enclosing rocks.

All along the west coast of Sakhalin, with the exception of the Mgachi area and possibly of Gornozavodsk (see Fig. 1), the transition from the Khoyndzhinsk tuff (Chekhov and Noda formation; see Fig. 2) is effected by an intermediate sequence having the features of both the underlying and overlying deposits. In the Aleksandrovsk area, B.M. Shtempel' (1948) and A.N. Krishtofovich before him (1920) distinguished these transition beds as the Cape Markevich beds; they are assigned to the lower tuffaceous unit of the Verkhneduysk formation, in the Boshnyakovo area (K. Kavasaki, [5]), Uglegorsk (A.A. Kapitsa, (1951), and Krasnogorsk (K. Uvatoko [11]).

The Verkhneduysk formation proper (as we understand it) rests upon the Khoyndzho formation (Chekhov, Noda) either quite conformably or with an erosional break, small in some places but an unconformity in others.

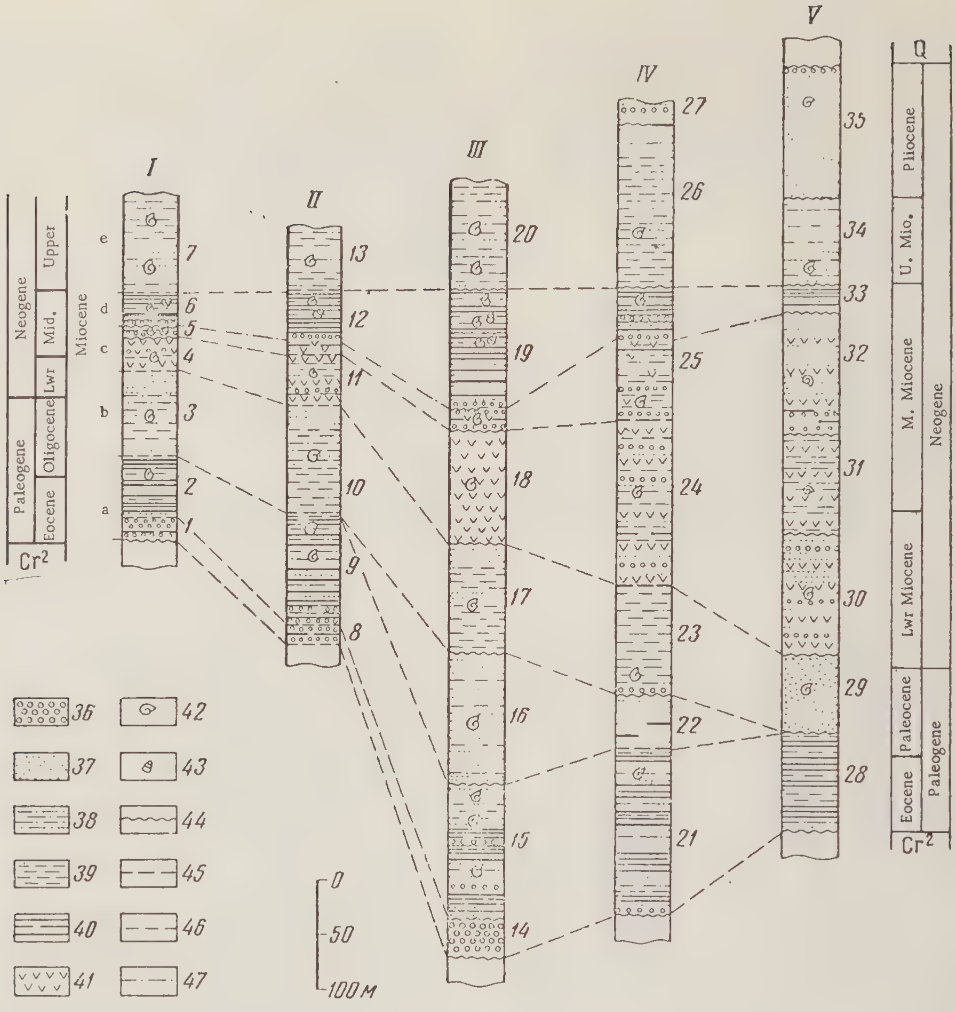

FIGURE 2. Generalized Tertiary Section of the Western Coast of Sakhalin.

I -- Aleksandrovsk area (after B.M. Shtempel', 1948); II -- Boshnyakovo-Lesogorsk area (after K. Kavasaki, 1935); III -- Uglegorsk area (A.A. Kapitsa, 1951); IV -- Krasnogorsk area (after K. Uvatoko); V -- Gornozavodsk area (after L.M. Sayapina, 1950); 1 -- Basal conglomerate; 2 -- Coal-bearing unit of the Nizhneduysk formation; 3 -- Gennoyshi shale; 4 -- Extrusive Khoyndzho unit of the Bennoyshi formation; 5 -- The Cape Markevich beds; 6 -- Verkhneduysk formation; 7 -- Unconsolidated formation; 8 -- Yokunay conglomerate; 9 -- Yokunay coal formation; 10 -- Gennoyshi-Nisisaku-Tan shale; 11 -- Akusyu volcanics; 12 -- Nayosi coal measures; 13 -- Onnay shale; 14 -- Basal conglomerate; 15 -- Nizhneduysh formation; 16 -- Krasnopol'yevsk formation; 17 -- Gennoyshi formation; 18 -- Khoyndzhao formation; 19 -- Verkhneduysk formation; 20 -- Sobolevsk formation; 21 -- Naybuchi formation; 22 -- Lower unit; 23 -- Upper unit of the Nisisakutan formation; 24 -- Noda formation; 25 -- Naykhoro formation; 26 -- Maruyama formation; 27 -- Chinnay formation; 28 -- Nizhneduysk formation; 29 -- Gennoyshi formation; 30 -- Tomarinsk formation; 31 -- Novoselovo formation; 32 -- Chekhov formation; 33 -- Verkhneduysk formation; 34 -- Sobolevsk formation; 35 -- Izyl'met'yevsk formation; 36 -- Conglomerate; 37 -- Sandstone; 38 -- Siltstone; 39 -- Argillite; 40 -- Coal beds; 41 -- Tuff and Tuffaceous rocks; 42 -- Marine fauna; 43 -- Brackish water fauna; 44 -- Unconformity; 45 -- Conformable sequence; 46 -- Formation coundaries; 47 -- Author's lower boundary of the Verkhneduysk formation; a -- Nizhneduysk series; b -- Khanadasinsk series; c -- Khoyndzhinsk series; d -- Verkhneduysk series; e -- Okobykaysk series.

The marine transgression at the end of ıe Middle and the beginning of the Late Iiocene is reflected in a gradual change of ıe Verkhneduysk continental deposits to the kobykaysk marine beds. In areas where the kobykaysk megacycle presents an unbroken equence, the upper boundary of the Verkhneuysk formation can be traced only conditionlly by its lithology and the amount of coal contains.

The southern part of the island is charcterized by local unconformities between a oal-less marine sequence (Kurasi, Onnay, urasiysk, unconsolidated (in part), and obolevsk formations) resting transitionally n the Verkhneduysk formation, and another narine sequence above it. The latter marine equence corresponds to most of the upper art of Okobykaysk formation (Maruyama, laruyamsk, partly Sobolevsk, and unconsoliated formations). Locally, the Okobykaysk negacycle has been eroded down to the pper and even middle Verkhneduysk units n the Krasnogorsk and Gornozavodsk areas, ig. 2, 3). At such places, the upper formaon boundary is quite distinct.

The extent of the Verkhneduysk formation f Sakhalin is understood differently by diferent investigators. Ye. M. Smekhov [10] onsiders the transitional tuffaceous beds as s basal unit. B.M. Shtempel' (1948) ssigned them to the Khoyndzhinsk formation, s the Cape Markevich beds; S.N. Alekseyhik, I.N. Kuzina and I.I. Ratnovskiy [2] ssigned them to the Khoyndzbinsk formation series), in the Aleksandrovsk area section Agnevskiy formation), and to the Verkhneuysk formation in the southern half of the sland. V.D. Kozyrev and I.I. Ratnovskiy 6] include the transition zone in the Alekandrovsk area in the Verkhneduysk formaon, while correlating its coal-bearing seuence with the entire Verkhneduysk formaon including the transition beds of the outhern half of the island.

In our opinion, the basic criteria for stablishing the lower boundary of this formaon are as follows: correlation on the basis f the index horizon and its specific facies nd lithologic characteristics in all sections f this formation; also the correspondance of Tertiary sequence separated from the wellnown Verkhneduysk formation of Krishtofich [8] by a coal-bearing sequence carrying umerous high-grade coal beds (which have een exploited for a long time). The lower oundary of the Verkhneduysk formation can e pinpointed by means of facies and geoectonic study of the Middle Miocene deposits.

The definitely volcanic upper Khoyndzhinsk ocks with a marine fauna change upward to sequence of interbedded, somewhat tuffaceous rocks of various granulometric composition and carrying a marine and brackish-water fauna and an abundance of plant remains and thin carbonaceous seams.

The comparatively fine-grained beds of the lower transition sequence change upward to coarser-grained beds with an increasing number of carbonaceous intercalations. In its upper part it contains a considerable quantity of continental deposits.

In areas of uninterrupted sedimentation, a strictly continental unit of coarse-grained, largely alluvial sediments (gravel and conglomerate) rests upon the transition section, marking the end of the marine regression.

This unit is overlain by continental marsh and lacustrine deposits changing upward to marine beds carrying exploitable coal seams. Sedimentary conditions of a stable shore line give place to a transgression with the deposition of essentially marine upper beds.

The differential positive movements at the beginning of the Middle Miocene resulted in the above-mentioned hiatuses in a number of localities, involving sizable intervals, among them the transition sequence deposited during the regressive phase.

Consequently, the oldest stratigraphic unit common to all occurrences of this formation is the one corresponding to the cessation of the regression and to the onset of stable conditions of continental sedimentation. This unit, represented by the coarsest-grained sediments, is the easiest identified macroscopically. Like the overlying beds, it carries no tuffaceous material, with the first exploitable coal occurring above the basal unit. The lower boundary of the Verkhneduysk formation should be drawn at the base of this stratigraphic unit.

Its upper boundary is unmistakable in those areas where the overlying sequence is unconformable upon it (e.g., in the Krasnogorsk and Gornozavodsk areas).

The upper boundary is arbitrary in those instances where the upward change of coal measures to marine deposits is very gradual. It may be conveniently traced at the top of the uppermost, primary sedimentation cycle that still carries continental deposits.

2. STRATIGRAPHY OF THE VERKHNEDUYSK FORMATION

a) General Considerations

Stratigraphic differentiation of the Verkhne-

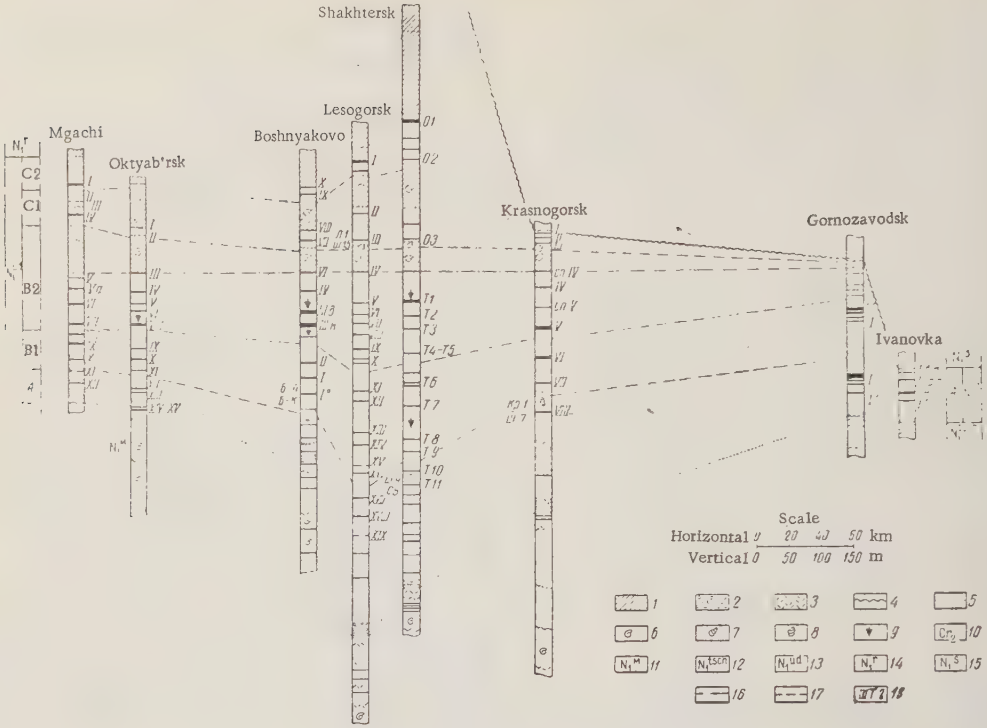

FIGURE 3. Stratigraphic relationships of profiles of the Verkhneduysk suite along the western coast of Sakhalin.

1 -- Marine deposits; 2 -- Fluvial deposits; 3 -- Tuffs, tuffite, tuffaceous rocks; 4 -- Unconformity; 5 -- Conformable sequence; 6 -- Marine fauna; 7 -- Brackish-water fauna (Corbicula); 8 -- Fresh-water fauna; 9 -- Trapa borealis Heer, water nut fauna; 10 -- Upper Cretaceous deposits; 11 -- Cape Markevich beds; 12 -- Chekhovsk formation; 13 -- Verkhneduysk formation; 14 -- Unconsolidated formation; 15 -- Sobolevsk formation; 16 -- Datum. Base of the lower marine unit; 17 -- Mesocycle boundary; 18 -- coal beds.

duysk formation is possible because of the differences in the amount of coal, in the thickness and grade of coal beds, and in the facies composition of its component members.

Early studies of coal deposits belonging to this formation consisted in identification of coal beds and the corresponding enclosing matrix. Thus, the "Makar'yevsk," "Duysk," and "Voyevodsk" coal beds were stratigraphically identified in the Duysk coal fields of the Aleksandrovsk area (B.M. Shtempel', 1948).

Further data on the lithology and origin of the coal measures made it possible to subdivide the formation into its stratigraphic components on the basis of lithology and facies, in addition to its coal content.

A.A. Kapitsa (1951) recognized four units in the Verkhneduysk section of the Aleksandrovsk and Uglegorsk areas. Reading upward, they are: the basal tuffaceous, and the lower, middle and upper coal-bearing units. The basal tuffaceous unit (the Cape Markevich or transitional beds of our classification) is represented, as a whole, by coarse tuffaceous rocks of various granulometric composition (ranging from conglomerate to argillite) with non-exploitable coal seams.

The lower coal-bearing unit is made up of normal sedimentary rocks of various grain sizes. It contains locally workable coal seams of low grade and small thickness. The middle coal-bearing unit carries the most coal and has a sand and silt composition. Numerous valuable economic coal beds occur here. The upper coal-bearing unit is the finest-grained in the section, with the coal beds separated by thick beds of silt and shale. Some of the coal beds are workable.

Facies of the basal tuffaceous unit include marine and fresh-water continental deposits; those of the lower coal-bearing unit are fresh-water continental beds. The middle coal-bearing unit consists of fresh-water continental deposits with some near-shore marine beds. The upper coal-bearing unit is

represented by littoral, marine and fresh-water continental deposits.

Finally, S. M. Malinin and Ye. G. Semenikhina (1955) came up with the latest stratigraphic scheme, on the basis of a lithologic facies study of this formation in the Uglegorsk area. They divide it into two parts corresponding to two facies complexes; the lower, a continental and in part littoral-marine sequence, and the upper, a littoral-marine, shallow marine and partly continental sequence.

It follows from the above exposition that the unpublished works on the Verkhneduysk section divide it into no more than three intervals (not counting the transition sequence). Their boundaries are purely arbitrary, since the authors (A. A. Kapitsa, 1951; S. M. Malinin and Ye. G. Semenikhina, 1955) generally concede a considerable variation in lithology and coal content throughout the area. Most often, the boundaries are drawn on coal beds which mark the contact between readily distinguishable members.

A common factor of all extant stratigraphic schemes of the Verkhneduysk formation is the identification of an essentially continental lower and an essentially marine upper part of the section. This regularity in upward change from continental to marine deposits is likewise present in other areas of the distribution of this formation. It is noted by Ye. M. Smekhov [10] for the southern part of Sakhalin; by S. N. Alekseychik [1] for the northern part; and by S. N. Alekseychik, I. N. Kuzina and I. I. Ratnovskiy [2] for the entire island. They all note the appearance of a marine fauna in all upper beds of this formation, marking the onset of a marine transgression.

Given the entirely inadequate state of knowledge of the marine fauna and flora of the Verkhneduysk formation and the somewhat "conservative" character of Miocene life, none of the present stratigraphic classifications is based on a substantial paleontologic foundation. All attempts at subdivision and correlation of this formation as it occurs in different areas are based solely on such criteria as facies similarities and differences, coal content, etc.

The results of the cyclic facies method of study of the west coast of the island afford the means of approaching the stratigraphic subdivision of the Verkhneduysk formation and a correlation of its sections with their geotectonic position.

On the basis of the latest stratigraphic chart, synchronous Tertiary movements may be regarded as proven, at least for the western coast of Sakhalin [2, 6]. Particularly important for our purposes is establishing the same age for the entire Verkhneduysk formation. As of now, it is accepted as Middle Miocene.

An analysis of facies change within the Verkhneduysk formation confirms the widespread nature of smaller oscillations which form the background for the coal accumulation. The widespread nature of these movements is manifested in the sharp "mesocyclicity" of the section, which is recognized from the regularity of facies changes in the primary sedimentary cycles. The mesocycles are identified from the change of so-called "transgressive" primary cycles to the "regressive" (beginning of a mesocycle), then to "stabilized" and back to "transgressive."

Since the Verkhneduysk formation, as a whole, has a well-defined "transgressive: character, clean-cut facially regressive cycles are rare at the base of its mesocycles. As a rule, a mesocycle opens with stable cycles and closes with definitely transgressive ones, as recognized from their facies content and the ratio of thickness of their pre-coal and post-coal sequences.

Mesocycles of a sequence represented by facially similar cycles are commonly differentiated according to the change in facies composition in rocks of a regressive part of primary cycles, such as coarse-grained lagoonal siltstone changing to medium-grained alluvial sandstone deposited in a basin.

The Verkhneduysk section of the western coast of Sakhalin contains five sedimentary mesocycles. Reading upward, they are: A, B1, B2, C1 and C2 (see Fig. 3). The mesocycles are designated according to their predominating conditions of sedimentation and coal accumulation. Thus, mesocycle A was formed along the lower course of a river valley; mesocycles B1 and B2, chiefly in a lagunal environment variously affected by alluvial conditions of lower river valleys; and mesocycles C1 and C2, in a shallow marine and lagoonal environment, with the marine predominating.

b) Brief Characteristic of Some Key Sections of the Formation

The method of cyclic facies analysis was used in the study of the following key coal deposits along the west coast, from north to south: Mgachi, Oktyabr'skiy, Ust'-Boshnyakovo, Lesogorsk, Shakhtezsk, Krasnogorsk and Gornozavodsk (see Figs. 1 and 3).

In the Mgachi area, the Verkhneduysk formation rests unconformably on Cretaceous

deposits (see Fig. 3).

Mesocycle A is represented by 3 to 7 primary cycles containing thin ashy coal beds or carbonaceous argillite, and consisting chiefly of coarse-grained alluvial deposits (fine, gravel conglomerate and gravel beds) with alternating marsh deposits. This mesocycle is 30 to 60 m thick.

Mesocycle B1 begins with alluvial gravel beds and sandstone, changing upward to sandy silt deposited in basins partly connected with the sea. These basin deposits (lagoonal, embayment, bar, delta, etc.) are best described as "transitional continental-marine," a term proposed by L.N. Botvinkina, Yu. A. Khemchuzhnikov, and others [4]. This mesocycle contains 3 to 4 primary cycles and 3 coal beds, one of which is workable. The mesocycle is 60 to 80 m thick.

Mesocycle B2 is very characteristic not only of the Mgachi but of other deposits as well. Generally beginning with deltaic, and rarely with alluvial or lagunal deposits, it contains comparatively thick but slightly ashy coal beds; it is terminated by a marine unit carrying an abundant pelecypod fauna and glauconite accumulations.

In the Mgachi section, where mesocycle B2 is 160 m thick, it consists of 6 sedimentary cycles and contains 4 coal beds of workable thickness.

Mesocycle C1 marks the return to lagunal conditions. This mesocycle, consisting essentially of sand and silt beds, carries 3 coal beds, one of which is of workable thickness. A characteristic feature of this mesocycle is the abundance of brackish-water Corbicula mgatschensis Sim. remains. The Corbicula horizon, which is present in the same section of other areas, has been accepted as a key horizon in B.M. Shtempel's correlation (1948) within the Aleksandrovsk area. The same distinction was attached to it by K. Kavasaki [5] who studied the Boshnyakovo-Lesogorsk area coal deposits. Mesocycle C1 is 20 to 30 m thick.

Mesocycle C2 (the formation's upper mesocycle) contains 2 to 3 primary cycles and a single workable coal bed. Its thickness is about 25 m. It is overlain by sandstone and siltstone deposited in an open sea (Unconsolidated formation); the contact is distinct. Facially, mesocycle C2, like C1, is primarily lagoonal.

On the whole, boundaries of megacycle B1 within the Mgachi section are arbitrary. The underlying mesocycle A is represented by a predominance of regressive primary cycles, and there are no clean-cut transgressive cycles in the upper part of mesocycle B1. Nevertheless, even in this sequence, mesocycle B1 may be identified from the alternation of primary cycles characterized by a different ratio of their pre-coal and post-coal portions and also from the fact that mesocycles A, B1, and B2 are sufficiently well identified in the Oktyabr'skiy section whose unit-by-unit correlation with the Mgachi section is quite authentic (B.M. Shtempel', 1948). The overall thickness of the Mgachi section is about 400 m.

A composite description of the Shakhtersk section of the Verkhneduysk formation is given here. Data from the A.A. Kapitsa ditch (1951) are used for the lower part, not opened as yet by exploration shafts and not clearly exposed in outcrops.

According to these data, the lower part of the formation (mesocycle A) is represented by alluvial sandstone and conglomerate grading upward to sandy and silty rocks with a fresh-water fauna. Nine cycles and as many carbonaceous layers may be identified within the mesocycle. The two upper coal beds have a workable thickness. The overall thickness is 200 m. That part of the section described from Kapitsa's data is designated as CB on Fig. 3.

In its lower part, mesocycle B1 is represented by regressive cycles with a wide development of deltaic deposits; in its upper part, by the lagunal or embayment cycle. It consists of 6 to 7 primary cycles and carries 6 workable coal beds. Its upper boundary, because of the obscure facies change, is arbitrary. Its thickness reaches 160 meters.

Mesocycle B2 of the Shakhtersk section is the lagunal or embayment type, less-commonly deltaic, in its lower part. Its upper, marine transgressive sequence carries a rich pelecypod fauna containing stenohaline forms. This mesocycle includes up to 8 carbonaceous beds, of which 4 to 5 are economically valuable. Accumulations of Corbicula have been found above the upper economic bed. The mesocycle thickness is 190 m, with 9 primary cycles.

Mesocycle C1 is very similar to that of the Lesogorsk section. It consists of two primary cycles in its regressive sequence, with one or two in the transgressive one, and terminates with a marine unit. A Corbicula horizon is identified at the base of the mesocycle, along the boundary with mesocycle B2. The mesocycle contains 2 to 3 coal beds, one of them workable, and is 120 m thick.

Mesocycle C2 consists of four primary

cycles, with the upper one definitely transgressive, judging from the ratio of its component parts, it also carries marine deposits. The number of carbonaceous layers is variable; two of the coal beds, however, are workable throughout the area. The arbitrary upper boundary of this mesocycle (and formation) results in an apparent general increase in thickness, making more than 220 m thick.

The total thickness of the formation in the Shakhtersk deposits is 900 meters.

The Gornozavodsk section of this formation differs sharply from the others in its thickness and coal content. However, a marine fauna, found under the upper coal bed in the northern part of the Gornozavodsk syncline, (V.P. Kirkinskaya, 1949) justifies the belief that stratigraphically the formation is represented here by the same part of the section as in the Krasnogorsk area.

The Verkhneduysk formation lies on the tuffaceous Chekhov formation with a sharp unconformity having all the earmarks of shallow erosion (see Fig. 2). In its lower and middle part, it carries definite alluvial and sand-gravel deposits. Mesocycle A, about 100 meters thick, has an alluvial cycle at its base and is terminated by a thick coal-bearing sequence including several minor marsh cycles. The overlying mesocycle B1 also begins with alluvium and is represented higher up by lacustrine and marsh deposits with thick coal beds. The overall thickness is 100 meters.

Mesocycle B2 belongs to transitional deposits, with a marine fauna present only in its upper part. Its overall thickness is about 60 meters and it contains several carbonaceous beds. A thin silty unit (about 10 meters thick) carrying a single coal bed and overlying a stratigraphic unit with a marine fauna, is the lowermost part of mesocycle B1 which was eroded prior to deposition of the Sobolevsk formation (see Fig. 2).

As established by detailed field work (V.T. Sheyko, 1956) the Sobolevsk formation rests on the eroded surface of mesocycle A along the southern edge of the Gornozavodsk coal area. Thus, the overall thickness of this formation ranges from 90 to 150 meters.

c) Lithologic and Faunal Key Horizons of the Verkhneduysk Formation

Going upward in the section, there are a number of horizons whose lateral extension affords a correlation of several sections on the basis of cyclic movements. These horizons are as follows: the top of a unit of coarse-grained rocks at the base of the formation; the Trapa borealis Heer horizon in its middle part; a glauconitic horizon in the lower marine sequence (upper part of mesocycle B2); the Corbicula horizon; and the upper marine unit (mesocycle B1). Some of them are local key horizons, but some others are identifiable over larger areas.

The coarse-grained unit at the base of the formation corresponds to the maximum Middle Miocene regression. It is built up of gravel, conglomerate, coarse sandstone, mainly of alluvial origin, and containing pebbles of flint, quartz, and extrusive, sedimentary and pyroclastic rocks.

The bed carrying Trapa borealis Heer, which is an index fossil for the Verkhneduysk formation as a whole [6], was first separated as a key bed in correlating of the Oktyabr'skiy coal deposits, as early as 1948, by B.M. Shtempel'. Trapa borealis occurs in various sequences within the formation, with its maximum accumulation occurring during deposition of a specific unit (lower part of mesocycle B2). Within the Oktyabr'skiy coal deposit it occurs only between the sixth and eighth coal beds.

The glauconitic horizon is identified by B.M. Shtempel' in several sections of this formation throughout the Mgachi-Agnevo area. It occurs in the middle part of the lower marine unit (upper part of mesocycle B2) and is of a local significance.

The Corbicula horizon was designated as a key for the Mgachi-Agnevo area by B.M. Shtempel' (1948); and by K. Kavasaki [5] and B.I. Mikheyev (1945) for the Boshnyakovo-Shakhtersk area. Poorly-preserved Corbicula shell remains have been found in the Krasnogorsk section.

A bed rich in Corbicula occupies a precise position in the formation (lower part of mesocycle B1). Despite the fact that the Corbicula fauna has a wide time range, this horizon may be accepted as a key for the entire western coast.

Unfortunately, faunas of the upper and lower marine units are not sufficiently well known to designate forms peculiar to either. These units, generally made up of uniform argillite and fine silt, are readily recognizable, however, by their lithologic features.

d) Main Geotectonic and Paleogeographic Features

Viewed on the Miocene tectonic background, Verkhneduysk time was one of stability and incipient submergence, first compensated by

sedimentation, then outdistancing it.

As a result of intense differential uplifts at the close of the Khoyndzhinsk time, and of the subsequent erosion, different deposits were brought to the surface in different areas of the island. Certain areas, not subject to such intense positive movements, were still undergoing "regressive" sedimentation accompanied by a gradually weakening volcanic activity and vestigial coal formation.

Verkhneduysk time is marked by five major sedimentary cycles common to the entire Mgachi-Gornozavodsk area. The middle one of them (mesocycle B2), which reflects the optimum conditions for coal formation (a small amount of compensated submergence and a broad coastal plain), has the maximum coal content.

Smaller oscillations were not general, their number and amplitude being different in different areas.

The sizable fluctuations in thickness of the Verkhneduysk formation within the western coastal area suggest differences in the net negative movements of the time. The formation as a whole thins down both north and south of the Shakhtersk coal deposit, attaining its minimum thickness in the Gornozavodsk area. Differences in the thickness are in the order of 900 to 350 meters (the minimum thickness, including erosion of the upper part, prior to deposition of the Sobolevsk formation). A change in the formation thickness is accompanied by a change in the number of primary sedimentary cycles and in facies of the coal measures.

It may be stated as a general rule that the number of primary cycles increases with the thickness of the formation, while the component coal beds grow thinner and the facies acquire a marine aspect.

Continental conditions prevailed over most of Sakhalin at the beginning of Verkhneduysk time. The presence of Cretaceous and Paleozoic pebbles in the continental basal rocks of this formation suggests that the Paleozoic and parts of the Cretaceous areas presented positive relief forms fringed by a broad zone in coal accumulated.

It is possible that some highlands were lying directly west of the present shore line. This is suggested by the coarser texture of the lower part of the formation along the western wing of the Mgachi syncline compared to its eastern limb.

A subsequent submergence and an intense erosion of highlands brought about a general levelling of the island surface. By this time (middle part of the formation) positive forms were present on Sakhalin only in the area of the East Sakhalin and Susunai ranges which were the sources of clastic material.

This long transgression almost fully obliterated even these sources of sediments; the latest traces of them are found in the lagunal deposits of the upper part of the formation.

3. SUMMARY

1. A cyclic facies analysis of sections of the Verkhneduysk formation along the western coast of Sakhalin makes it possible to subdivide it into five mesocycles (A, B1, B2, C1, C2) corresponding to the five stages of Middle Miocene coal accumulation: essentially continental, continental-lagunal, lagunal, lagunal-marine, and essentially marine.

2. Depending on the character of the periodic movements (i.e., an amplitude, and rate), different sections of the formation contain a different number of sedimentary cycles. However, the comprehensiveness of major movements makes it possible to correlate even distant sections by their mesocycles which are represented in the section (especially in the upper part of the section).

3. Correlation by mesocycles is corroborated by a number of key horizons which maintain their lithologic and faunal characteristics throughout wide areas.

4. The lower formation boundary should be drawn on the coarsest stratigraphic unit at the base of mesocycle A, and common to all sections.

5. In most instances, the upper formation boundary cannot be determined with certainty. It should be drawn arbitrarily on the upper boundary of the upper cycle which carries continental deposits, i.e., on mesocycle C2.

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PROBLEMS IN THE STUDY OF BASALTIC MAGMA

by

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Problems involved in the study of basic rocks, the origin of basalt and associated magmas, the character of their differentiation, etc. continue to attract the attention of modern petrology. This is because they aid in the solution of many fundamental problems of this science, such as the prime source of magmatic material of the earth's crust, the nature of subcrustal substances, the structure and composition of deep layers, the details of magmatic processes in the platform and mobile zones, the crystallization and differentiation properties of several types of magma under different geologic conditions, the character of post-magmatic mineralization, etc.

Some of these topics are dealt with below, on the basis of the latest published domestic and foreign data, also from field data on basic rocks of the Soviet Union, more specifically on the traps of the Siberian Platform.

By basalt magma is meant here all near basalt magmas known to occur in the earth's crust.

THE ORIGIN OF BASALT MAGMA (PROTOMAGMA) OR MAGMAS

The nature of ancestral magma (protomagma, after F. Yu. Levinson-Lessing) or of basaltic magmas is dependent upon the structure of the earth's crust and its deeper geospheres. The origin of this ancestral magma is not yet solved, inasmuch as the chances of proving one or another hypothesis are very small.

Without pausing here for general problems of the origin of the earth and its crust, we will outline the current ideas on the earth's crust as it is now.

The Washington and Daly theory of the internal structure of the earth -- the most interesting for a petrographer -- is in general agreement with the V. Goldschmidt-A. E. Fersman scheme. We are most interested in the upper crust, down to about 1,000 km (the focus of deep earthquakes). The petrographic aspect of the structure of this upper envelope was worked out in comparatively great detail by A. Buddington [12]. His scheme, essentially a compilation of contemporaneous ideas, is as follows (depth in kilometers):

0-15	Granite
15-25	Quartz gabbro and gabbro
25-30	Bitovnite anorthosite
30-38	Olivine gabbro and norite
38-70	Pyroxenite, peridotite, dunite
70-500	Vitreous peridotite enriched with superfusible components; changing upward and downward to crystalline peridotite
500-1000	Crystalline peridotite
1000-2900	Transition zone: on top -- similar in composition to chondrite meteorites; at base -- to pallasite meteorites
2900-2920	Sulfide layer
below 2900	Iron-nickel core

As a substantial complement to the previous schemes, we have here the differentiation into subzones and the introduction of an anorthosite layer whose existence is assumed on geophysical and petrologic data. Despite its hypothetical character and the lack of precise substantiation by actual data, especially the depth of individual zones, this scheme is of interest because it satisfies better than any other the geophysical and petrologic data on the distribution of elements in the earth's crust according to their density, the sequence of magmatic processes within individual magmatic cycles, etc. To a certain extent, it is a working hypothesis.

The existence of a continuous peridotitic or sima envelope is accepted by nearly all authors engaged in studying the structure of the earth's crust. There is a difference of opinion, however, on the structure and composition of upper zones, especially of the basalt layer. For instance, V.N. Lodochnikov, in his time, voiced a doubt as to the existence of zones differing in composition, insofar as a density change within the earth may be due to the state of matter rather than to the composition change at different depths. Other authors held the same ideas, later on. However, these arguments are controversial in their very nature. It must be admitted that the theory of a zonal structure of the upper part of the crust, with each zone

having a different petrographic composition, appears to satisfy the data of petrology, geochemistry and geophysics. On the other hand, the coubts on the continuity of these envelopes or geospheres, all around the globe are still valid. Differences in the structure and thickness of individual geospheres undoubtedly do exist in structurally different segments of the crust underlying oceanic troughs and continental blocks, as they probably do in individual parts of the latter. It appears to be more correct to assume the existence of certain differences in the thickness of individual zones in individual segments. A continuous basalt or gabbro layer does not everywhere fit the geophysical data.

The upper boundary of the peridotite zone is not found at the same depth everywhere. According to oceanographic data, it is most likely to lie some 15 km below the ocean bottom; 10 to 40 km below the continents; and the deepest below the platforms, at about 40 to 60 km.

A confirmation of the existence of a deep peridotite layer is sought in both the geophysical and petrographic data. In this connection, C. Ross, M. Foster and A. Myers critically analyze the existing data on the structure and composition of dunite inclusions known to be characteristic of the basic rocks of many regions. They gave especial attention to basalts of Germany distributed there with their two belts of dunite inclusions, the northern and the southern. The authors came to the conclusion that a majority of the dunite inclusions in basalts are not a segregation of olivine grains in basalt magma, but originate rather in deeper peridotite zones, and get into the magma in a semi-crystalline state, which is proven by the presence in them of protomagmatic (banded, etc.) structures.

H. Powers [33] finds a corroboration of this hypothesis in volcanologic data. In analyzing data on the composition of Hawaiian volcanics, he perceived their relationship with a deeper peridotite zone. He rejects the whole idea of a basalt layer. He assumes, instead, that the pyroxene-plagioclase eutectics were extracted from a peridotite zone as a result of an abrupt change in temperature and pressure during periodic tectonic stresses. A basalt magma with such an origin acquired, especially in its initial stages, a great mobility because of its great volatile content. The appearance of alkaline, ultra-basic and other separations is connected with later processes of differentiation in secondary hearths and is purely local in character.

The second half of this hypothesis, dealing with the evolution of basic magma, explains fairly well the origin of diverse Hawaiian lavas and should explain to a certain extent the magmatism of other regions, especially of the Siberian traps. However, in rejecting the whole idea of a basalt layer, the author undoubtedly is at odds with other known facts of geophysics and petrology.

The above-named scheme of different petrographic zones affords a satisfactory explanation of the origin of diversified magmas which subsequently enter the upper layers of the earth's crust or come out to the surface. W. Kennedy and E. Anderson [25] evolved a graphic scheme explaining the possibility of origin of one or another magma in either a partial or complete melting of matter in the corresponding geospheres. A similar, slightly modified diagram was presented by A. Bauddington ([12], Fig. 2). In his scheme, as soon as a geoisotherm reaches any given layer, the layer yields a magma of a corresponding composition. Under favorable tectonic conditions, this magma may enter the upper zones of the crust.

While admitting the general orderliness of this hypothesis, it should be kept in mind that such a picture of a zonal structure of the earth's crust is complicated to a considerable extent by the lack of lateral uniformity in structure and composition of geospheres. This should strongly affect the processes of magma genesis in different provinces. It is evident, furthermore, that a differential fusing of a gabbro or peridotite substratum does not necessarily lead to the appearance of a corresponding magma, because the lower temperature eutetics may be separated first.

All told, it must be admitted that the conception of magma genesis as a result of periodic fusing of certain geospheres is the most consistent interpretation of magmatic phenomena.

An analysis of data on the composition of the upper geospheres, with reference to the distribution of the alleged basalt substratum, forces the assumption of certain possibly considerable differences between mobile (geosynclinal) zones and platforms and oceanic troughs. We shall return to this topic, in more detail.

The problems of the interior of the crust and of the processes which transfer the magmatic material from the depths to the surface are closely related to the movements of subcrustal currents. The existence of such currents is more and more confirmed by geologic and geophysical data. The main premises of the hypothesis of subcrustal currents are as follows: 1) a gradual cooling of the earth; 2) a plastic subcrustal layer. According to Pickeris (1935), A. Holmes (1949) and other authors (cited by V. F.

Bonchkovskiy, [2], the differences in temperature on the same hypsometric levels in the crust under oceans (average depth 4 km) and under continents (average elevation 2000 m) should unavoidably lead to an upward displacement of matter in the continental blocks, and to a downward displacement in the oceanic provinces. These displacements must be accompanied by compensating horizontal movements, from continents to oceans in upper geospheres, and in the opposite direction in the lower.

V. F. Bonchkovskiy [2] presents a graphic scheme of such currents originating in connection with the disposition of isometric and isobaric surfaces throughout the border zones between continents and oceans.

According to F. Vening-Meinesz [30], these currents originalte periodically whenever the temperature gradient rises enough to overcome the elastic limit of the corresponding segment of the earth's crust. Obviously, such processes would, first of all, set in motion the basalt magma. At the same time, V.V. Belousov [1] believes, this transfer of matter is probably connected with the continuing process of differentiation taking place at great depths, perhaps deeper than 100 km.

The idea of periodic transfer of basalt magma during the formation of platforms and their fringe of folded structures may be deduced from an analysis of the magmatic history of a platform with its trap formations. Thus, the history of development of the Siberian trap formation [4, 6, 7] suggests a probable coincidence of activation of the trap (basalt) magma with epochs of maximum platform fringe folding. This regularity is best explained by the hypothesis of major subcrustal horizontal drift.

The following petrographic example, cited by A. Holmes [19], Fig. 4) seems to substantiate the hypothesis of a comparatively long distance migration of subcrustal matter. While studying a belt of dolerite dikes in northern England, that author noticed a regular change in the dolerite composition along the trend of the belt and inferred a magmatic movement east from a center in the area of the Island of Mull. Systematic studies may uncover similar instances in many other areas.

Despite its weak points, the hypothesis of subcrustal magmatic flow provides a fairly satisfactory explanation of many regularities in the development of magmatism in different provinces. As such, it deserves further study.

TYPES OF BASALT MAGMA

According to geologic data on hand, the phenomenon of upward flow of molten basalt magma, taking place during definite periods of the earth's history, is no longer open to doubt. The deep-seated origin of these magmas and their probable common source is suggested by their wide distribution and by the relative consistency in their overall composition. Their composition frequently is strikingly uniform throughout vast areas and over long geologic epochs.

The most comprehensive data on the composition of this molten substance are obtained from extrusive basalt and hypabyssal (essentially trap) formations, relatively poorly differentiated compared with intrusive formations, and less affected by subsequent events such as assimilation phenomena, etc.

Among those petrographers who favor the idea of a single basalt layer (as a primary source of basic magmas or of all extrusive rocks) are A.N. Zavaritskiy and V.I. Luchitskiy, in the Soviet Union; and N. Bowen and others, abroad.

However, a closer study of data on the geology, petrography and chemistry of secondary basalt formations has long suggested to investigators the existence of several types of basalt magma. Most popular was the idea of two main types, advanced in connection with the recognition of several local types of association of basalt with other volcanics. In 1922, G. Washington proposed the idea of 1) enstatite-augite basalt (platobasalt) and 2) aegirine-augite basalt. After him, W. Kennedy [24] further developed the idea of the independent existence of two types of ancestral basalt magmas: the "olivine-basalt" and the "tholeiite." According to him, the olivine-basalt magma, chemically more basic and carrying more magnesium, is peculiar to oceanic provinces. Its evolution is in the alkaline direction. The tholeiite magma, being somewhat richer in silica and alkalies, is peculiar to continental provinces and evolves into quartz-bearing and granophyre rocks such as dacites and trachytes. The direction of differentiation within a magmatic (basalt) province depends, according to W. Kennedy and C. Fenner [15, 24], solely on the composition of the original magma and very little, if at all, on the geologic conditions.

M. and A. Wells [40] proposed a more rational nomenclature for Kennedy's magmatic types, naming them respectively, sima (olivine-basalt) and subsial (tholeiite) types of basic magma.

A somewhat broadened classification of the

ısalt family magmas was evolved by P. Nig-
i and C. Burri [13], which distinguishes
etween three magma types: 1) normal basalt,
sub-basalt, and 3) alkaline basalt.

Detailed studies of individual basalt and
ap provinces, undertaken in the last one or
o decades, have done little for W. Kenne-
's hypothesis of two separate basalt mag-
as. It has been found that representatives
both the olivine-basalt and tholeiite mag-
as, with their typical differentiates, occur
gether in many provinces and even within
e assumed confines of a single magmatic
earth. Thus, according to F. Walker and
. Poldervaart [11], dolerite magma of the
aroo formation (South Africa) gravitates
ward the tholeiite type, in its average
omposition, while the average composition
magmas of other regions, such as Trans-
ei, are much nearer the olivine-basalt type.
he same is true for magmas of the Deccan
aps of India, where representatives of dif-
rent magmatic types and of different direc-
ons of differentiation are brought together
3]. According to A.P. Lebedev [4], the
erage composition of the Tungus depression
ap magmas (western part of the Siberian
atform) is intermediate between the two
ısalt magmas of W. Kennedy. In their min-
ralogic composition, these rocks are nearer
the olivine-basalt type because of the con-
ant presence of olivine. In the composition
their differentiates, on the other hand, they
avitate to the tholeiite type. The basalts
Iceland, according to A. Holmes [18], do
ot belong to either the alkaline nor the cal-
reous series but combine the features of
oth. Basalts of Greenland and Faroes
lands, according to Noe-Nygaard [31], con-
in both the alkaline-earth and the more acid,
ntaminated basalt magmas. According to
. Macdonald [29] and other authors, the
awaiian basalt province houses both evolu-
onary lines of the basalt series -- the
kaline and the trachytedacite.

C. Tilley [36], after a critical examina-
on of data on the Hawaiian lavas, came to
e startling conclusion that they are related
the tholeiite type magma rather than to
e olivine-basalt type as might be expected
om the typically oceanic position of this
ovince. In his opinion, the characteristic
rection of evolution of these lavas is pic-
te-basalt--olivine basalt--hypersthene
ısalt. This is essentially analogous to the
rresponding series of the Karoo dolerites,
lisade dolerite, and other continental prov-
ces.

Features of a tholeiite (i.e., "continen-
l") type magma are recognized, according
Tilley, in a number of other oceanic prov-
ces, such as Reunion Island (volcano Piton
la Fournaise), Tahiti and other places.

Tilley believes that this is proof that an olivine-basalt magma may be a source of both the "alkaline" and the "tholeiite" lines of evolution.

To explain this coexistence of different types of basalt magma, some authors regard the tholeiite magma as secondary, originating in the process of assimilation of material from the upper sial zone of the crust by olivine-basalt magma. This conclusion was reached, for instance, by H. Kuno [26] on the basis of his detailed study of recent lava of the Hakone volcano and of adjacent islands of the Pacific. According to Kuno, two series of volcanics are represented in that province, each ranging from basalt to andesite and differing in their chemical properties and in the composition of two types of rock-forming pyroxene: 1) pyroxene containing only pigeonite, 2) pyroxene containing hypersthene with or without pigeonite. The first of the two series (pigeonite) originates in fractional crystallization of olivine-basalt magma; the origin of the second series is related to the assimilation of acid rocks by the same magma. Because of a higher concentration of volatiles in the contaminated magma, in this process, the magma solidifies at a lower temperature, encouraging the formation of hypersthene in the resulting rocks. A proof of the importance of assimilation in the formation of rocks of the second series, is the presence of foreign crystals of quartz and acid plagioclase, and at times of granite xenoliths (as in lavas of the Nazu and Zao volcanoes).

Tilley believes, on the other hand, that the hypothesis of the tholeiite magma being formed at the expense of olivine-basalt magma is hardly tenable because it is contradicted by the chronologic sequence of lava flows, such as those of the Hawaiian Islands. He believes that the primary magma there was most likely tholeiite, having originated in the fusion of one of the upper lithosphere zones. A series of alkaline basalts of the same areas, on the other hand, originated as a result of certain modifications in the normal course of crystallization of the same tholeiite magma.

A correlation by J. Green and A. Poldervaart [17] of average chemical compositions of basalt of the Pacific Ocean (12 areas, 116 analyses), the Atlantic Ocean (9 areas, 25 analyses) and of the computed averages for Precambrian, Paleozoic, Mesozoic and Cenozoic basalt, leads these authors to the following conclusions: 1) average sial (continental) basalts are undersaturated with SiO_2, i.e., they are nearer the olivine-basalt type magma of Kennedy; 2) no regular change in the average composition of basalt magma occurs during individual epochs; 3) there are no

definite, chemically average basalt magmas; rather, there are series ranging from the tholeiite to the undersaturated types. In the opinion of these authors, these conclusions are on the whole in agreement with the hypothesis of a periodic formation of basalt magma in the processes of fractional fusion of upper zones of the earth's crust.

It follows from the above review that neither the hypothesis of a single ancestral basalt magma nor that of two basalt magmas explains the diversity of natural phenomena observed. One has to postulate the probability of existence (or periodic origin) in the crust of many types of basaltoid magmas whose subsequent evolution has resulted in the multiplicity of natural associations.

The same conclusion is reached by a study of evolution in individual magmatic complexes, as related to the activity of the primary magma. These specific evolution in features of individual basalt complexes or series are illustrated in the triangular diagrams, ($Na_2O + K_2O$:FeO:MgO), proposed by L. Wager and W. Deer [38]. Certain dolerite and basalt formations, as well as the Skaergaard complex of Greenland, contain the best expression of the tendency for iron accumulation, during practically the entire course of their development. Only in the last stages did an accumulation of silica and alkali develop. On the other hand, formations including lime-alkaline members (basalt-andesite-dacite-rhyolite associations) definitely exhibit another type of evolution, without much iron enrichment. This is possibly explained by assimilation of acid sial material ([38], Fig. 5). These differences stand out very graphically on the Poldervaart-Elston [32] diagram. There, the ratio of magnesium atoms to the sum of Mg and Fe atoms, characterizing a gradual change in the ferromagnesian portion of the molten mass, are plotted along the vertical axis, with the so-called bond factor plotted along the horizontal axis. The bond factor characterizes the strength of bond in the lattice structure of end minerals. In our case, it has the maximum value in the olivine structure (closely packed SiO_4 tetrahedrons); the minimum in the structure of amphiboles and chlorites (minerals with a looser packing). It follows that this bond factor generally decreases in the transition to more acid members of the series.

As given in that diagram, the curves for the Karoo dolerite, differentiated Stillwater, Skaergaard complexes, the intrusive complexes of Garibal-Hills and a California batholith also suggest differences in the direction of evolution in different series, the dolerite-basalt and lime-alkaline, in the present case. Here, the differentiation is expressed chiefly in accumulation of feldspar and in more definite fractionation as compared with femic minerals. The authors of the diagram also conclude that the origin of lime-alkaline rocks was greatly influenced by accumulation processes accompanied by fractional fusion of sial rocks, and also by the presence of water.

Another line of investigation to be followed in determining the origin of independent types of basic magmas with different lines of evolution is to connect these types with the differences in tectonic environment during formation of a given magmatic association. The main problem here is the specific chemical composition of magmas and the direction of their evolution in orogenic and non-orogenic zones of the earth's crust. The petrographic achievements here are considerably smaller than in the interpretation of purely chemical and mineralogic properties of basic rocks and their associations in individual complexes and provinces, as was mentioned before.

Of interest in this connection are certain conclusions by Tilley [36] who emphasized the comparative wealth in alumina of the andesite-dacite series of Oregon, and Lassen Peak, Modoc (California) which are examples of orogenic rock associations. He suggests the following genetic types of basalt series in orogenic zones: 1) tholeiite; 2) composite, derived from tholeiite; and 3) composite, representing the basic differentiates of intermediate andesitic type lava. Tilley rejects the possibility of a single evolutionary line for all these types of magma, each with individual properties of its own but he emphasizes the importance of assimilation processes in the genesis of individual series.

Finally, the geochemical line of investigation is very promising. It brings forth clear geochemical differences in rocks of different series, including both the orogenic and non-orogenic; this has been done to a certain extent by P. Lundegardth [27, 28] for the orogenic and non-orogenic series of Swedish hyperbasites. Not much has been accomplished in this field, as yet.

On the whole, these are the existing data on the subject of individual types of basalt magma.

As seen from the above review and from the data on the trap, basalt and andesite provinces, the following ideas seem to be substantiated:

1. There are several types of basalt magma, each with their own evolutionary lines.

2. The concept of two main types of basalt magma -- the continental and the oceanic

or tholeiite and olivine-basalt) -- first over-simplifies the complexity and multiplicity of basalt magmas in nature; second, it does not ully reflect their actual relationship with he geotectonic features of the crust.

3. These concepts inadequately reflect the enetic aspect of the problem, i.e., they eave essentially unanswered the question of he prime causes of differences in composi-ion of ancestral magmas.

4. In reality, there probably are several ypes of primary magma of a composition ear to basalt, and with evolutionary lines f their own.

It should be noted, then, that the accu-mulated petrologic data suggests the idea of polymagmatism", i.e., the multiplicity of nagmas in the earth crust, at different per-ods in its development -- of magmas period-cally developing at different levels of deeper eospheres and characterized subsequently y different lines of development, depending n their geotectonic position and initial chem-cal properties. The paucity of precise data n the composition and development of mag-nas as a function of a particular geologic nvironment hampers the solution of prob-ems of tectonomagmatism and gives high riority to their study.

TYPES OF DIFFERENTIATION (CAUSES OF THE DIVERSITY OF ROCKS IN THE BASALT SERIES)

To explain the diversity of rocks, as com-onents of basalt or gabbroid series, and in erms of their geologic form, petrographers earch into various processes involving frac-onal differentiation, diffusion convection, nagmatic splitting and liquefaction, gas trans-er, assimilation and hybridism.

Much attention is given, especially by the nglish and American authors, to fractional ifferentiation, although it does not explain number of geologic facts, as has been oted on many occasions (e.g., the recent aper by U. Masai, [8]). The application f this theory in explaining the mechanics f rock formation in certain basalt provinces, hiefly the oceanic ones, was discussed above I. Kuno's work on the Hakone volcano [26]; . Wentworth and G. Macdonald's [41] on awaii, and others). Understanding of the auses and processes of origin of individual arieties of lavas as a result of separation r addition of previously isolated inclusions f olivine or other minerals is sometimes elpful in arriving at a satisfactory explana-on of the formation of individual rock types. owever, this is not always the case, as the authors themselves note. Oftentimes, even the confirmed "bowenites" have to reach for concepts of contamination of a molten magma by foreign matter (see Kuno's explanation of the Hakone hypersthene series which is men-tioned above and other works).

In our opinion, any application of this (as well as any other) theory must be with refer-ence to a specific geologic situation; this, unfortunately, is not always done. While it may be possible to trace with a fair degree of certainty the course of differentiation or some other alleged magmatic process in small bodies, massifs, volcanic necks, etc., it is an altogether different thing to interpret these processes for abyssal bodies, in bodies having deep roots in orogenic provinces, or else from the data of entire provinces or formations. These complex situations require a particularly critical interpretation of var-ious hypotheses, specifically that of fractional differentiation, and most especially when they are applied without a complete analysis of the geotectonic conditions.

Along with the development of the frac-tional differentiation theory, petrographic thought has been more and more directed to other processes whose effect is manifested either in conjunction with that of fractional crystallization or independent of it. The phenomena of diffusion and convection un-doubtedly must be given a leading part in explaining the processes of cooling of basalt sheets and hypabyssal intrusions. The signi-ficance of these processes was emphasized early, by certain petrographers: F. Grout [16] for the Duluth complex; L. Wager and W. Deer [38] for the Skaergaard complex[and by some others. H. Cornwall [14] believes that the cooling of the Keweenawan basalt sheets of Michigan should have been accompanied by convection, as a combined result of cooling above and compaction below. W. Wahl [39] advanced an interesting hypoth-esis of composite diffusion-convection which, in his opinion, is important in the cooling of intrusive bodies, especially the hypabyssal ones. These processes bring about the forma-tion of generally more basic fringes of in-trusions, both in dikes and sills. A small difference in temperature is sufficient to evoke the diffusion-convection processes. It should be added that these processes undoubtedly are no less important in the course of magmatic differentiation in deep hearths. A reference to the processes of mag-matic differentiation, including diffusion and convection, is necessary in explaining the differences in the composition of individual portions of molten magma which periodically surge up from a deep hearth. This is espe-cially true for recurrent extrusions and in-trusions.

An ever-increasing importance is attached to the phenomena of both local and deep differentiation in explaining the processes of pneumatic differentiation and liquefaction. Without these concepts, it is difficult to explain the origin of diabase-pegmatoid segregations or larger segments of diabase intrusions. In 1934, on the basis of his study of dolerite and tholeiite sills of northern England, S. Tomkeef [37] concluded that, in the crystallization of basic magma in horizontal layers, a downward movement of nascent olivine takes place, along with the rise of volatiles. This led to the formation of diabase-pegmatite segregations in the upper levels of horizontal bodies. According to H. Cornwall, volatile components in basalt sheets of Michigan accumulated during the crystallization of middle parts of these sheets, the solubility of volatiles increasing with cooling (1% for each 50° C, according to Bowen). In this process, a temperature gradient was established between a given layer and the adjacent ones. The effect of volatiles caused autometamorphic changes in the solidifying substance. According to Conwall, the residue remained liquid, down to approximately 750°, being squeezed into fissures and cavities of the partially-solidified intrusive body.

The accumulation of volatile components in upper parts of crystallizing bodies is unquestionably demonstrated in certain Siberian trap intrusions. According to A.P. Lebedev [4, 6], it is demonstrated there not only in differences in the mineralogic composition of rocks in different parts of a cooling body, but also in essentially different courses of crystallization of the trap magma itself, in upper and lower parts of the intrusions. In its lower parts, the trap magma crystallizes in standard ophitic and poikilophitic structures; in its upper parts, in the pegmatoid and prismatically ophitic. The physical and chemical conditions of such processes are not well known, as yet, and existing hypotheses are in need of experimental confirmation. On the whole, however, the significance of differential distribution of volatile components in a cooling magma is not to be doubted.

DEPTH OF SOLIDIFICATION, THE NATURE OF CONDUITS, AND THE MECHANISM OF INTRUSION

It is obvious that the solidification depth of a magmatic body, together with its size and geotectonic environment, is one of the main factors determining the composition and structure of its end rocks. This is graphically demonstrated by basic rocks, especially by traps. These factors are especially to be considered in explaining the structure and composition of hypabyssal and near-surface bodies, where their influence is stronger than in larger abyssal bodies. All these problems, however, are as yet far from being worked out.

The solidification depth of magma and the nature of magmatic space is closely related to the mode of origin of magma conduits and to the mechanism of magma rise during an active period. Two modes of intrusion are possible in the case of a platform intrusion: 1) magma was intruded by pushing apart the walls of pre-existing fractures and hollows in the crust (view of Du Toit and others); 2) magma was intruded as a result of shifting of entire upper blocks, passively changing places with them (F. Yu. Levinson-Lessing, Scholtz, and others). Most investigators accept the concept of active intrusion of basalt magma, especially in platform provinces. This view is supported by our data on the trap sheet intrusions of the Siberian platform, emplaced in stratified rocks of the upper structural stage. The concept of a rise of trap magma under intensive pressure is held by P. Hotz [20] in his description of the mechanics of emplacement of the Pennsylvania trap sills. A somewhat different intrusive mechanism is ascribed by A. A. Polkanov [9] to sheet-like basic plutons emplaced in crystalline rocks. A solution of this problem for each specific intrusion calls for a fairly complete picture of the structure of a magmatic body at depth, which is not always available. The true three-dimensional structural picture of intrusions is commonly considerably more complicated than it appears from the surface. An example is the Landrid-Wales trap laccolith, studied in detail by O. Johnes and W. Pugh [22] from drilling data. The laccolith turned out to be a multitude [315] of small bodies, "microlaccoliths" or "microsills," located close to each other in Silurian shale. Below, there is a zone of feeder channels, presenting in a cross-section thin ducts numbering about 100. In the authors' concept, the magma came up either through a network of fissures, or else these fissures were joined at depth to form a single major conduit. On the whole, the magma has filled only about 25% of the volume of the allegedly massive laccolith. This explains the lack of curvature and uplift in the laccolith roof -- this despite an active intrusion which took place under considerable pressure.

Extremely interesting are the causes of magma rise in intrusions and extrusions, and the factors which bring about high pressures and temperatures in a surging magmatic column. Assuming, on the basis of geophysical data, a thickness of the sial envelope of 10-12 km, and that of the overlying sediments of 3 to 4 km, on the average, the

depth of the origin of magma, and consequently the length of the path it is to travel through the crust, comes to no less than 17 km (although hearths of intermediate depth may be assumed to exist). If the load of an overlying rock column is decreased as a result of a continuously open vent, the magma may receive an upward impetus. Water vapor must be assigned the most important part in raising the magmatic pressure and in supplying the magma with additional mechanical and thermal energy. According to volcanologic data, lavas carry 70 to 90% water as their gaseous component. If the enclosing rocks are impervious to vapors, the latter cannot escape the magma and will push it upward. The intrusive force of a magma depends on 1) the pressure of contained gases and 2) the temperature. With the water vapor escaped and the pressure of the overburden relaxed, heat will be liberated and the magma temperature correspondingly lowered. Consequently, the temperature in upper levels of a magma column will be much lower than at depth. Thus, the weak thermal effect of a basic magma on lateral rocks is explained by its relatively low temperature at the contacts. However, the origin of the high temperatures necessary in fusing a supposedly solid substratum, and of the enormous periodic surge of pressure at the same hypothetical depths, remains obscure.

We believe that a classification of the present data on the form, size, geotectonic position and intrusive mechanism of trap and similar hypabyssal basic intrusions would result in at least three structural types: 1) intrusions of the upper, stratified structural stage of ancient platforms; 2) intrusions of the lower structural stage of a platform; 3) intrusions of folded zones, subdivided into pre-orogenic, syn-orogenic, and post-orogenic subgroups.

Most of the trap intrusions of the Siberian platform and Karoo may be assigned to the first type; the second type will include a majority of trap intrusions in ancient shields such as Fennoscandia, Deccan, Canada and others; the third will include trap and diabase intrusions of central Caucasus, (Jurassic), Taymyr (Byrranga range), Pennsylvania, and other regions.

It goes without saying that, in solving the above problems, petrographers should be assisted by volcanologists who study the causes of periodic advent of high temperatures and pressures accompanying volcanic eruptions.

PHENOMENA OF CONTAMINATION AND HYBRIDISM

Voluminous and interesting material has been gathered in recent years bearing on contamination and hybridism. It tends to emphasize the great importance of these processes in the formation of acid and intermediate members of basalt and trap series. It should be kept in mind that two groups of phenomena are dealt with in this discussion:

1) The processes of hybridism, which take place at the immediate contact of a cooling magmatic body with the country rock. They lead to a partial assimilation of foreign matter by that rock and to the phenomena of rheomorphism. These processes take place at comparatively shallow depths.

2) The processes of contamination, leading to a more complete assimilation of foreign inclusions by the magma and the resulting appearance of rocks of an abnormal composition (in relation to the magma). These processes, as a rule, take place at greater depths.

The phenomena of group one have been dealt with in the petrographic literature (works of D. S. Belyankino, D. Sederholm, and others). Hybridization phenomena in Iotnian diabase of the Satakunt area (Finland) were recently described in detail by A. Kahma [23]. Here, the diabase forms an irregular body within Rappakivi granite and in the emplacing Iotnian sandstone and sends off apophyses into these rocks. Locally networks of thin, irregular veinlets of amphibole (up to 2 cm thick) carrying micropegmatite shoot off from a Rappakivi body into the contacting diabase. Chemically, the material of these veinlets is a granite somewhat enriched in Mg, Fe, Ca, and Na, and therefore belonging to the upper part of the "residual" crystallization field for granite magma on the Shairer-Bowen triangular diagram [35], where the fusion temperature is about 1,000° C. Insofar as this temperature is close to that for diabase, it may be supposed that diabase magma fused a corresponding eutetic mixture out of the Rappakivi granite or the sandstone. According to the author, the relative enrichment in Mg of the substance of the rheomorphic veins was a result of the comparative mobility of Mg.

In the instances when the lateral rock is more soluble, the boundaries between diabase and this rock become more or less obliterated. Thus, in the Suontaka region, xenoliths of hybridized rocks of intermediate (diorite) composition are emplaced in the diabase. In addition to the diabase minerals, these xenoliths contain quartz, alkaline feldspar, serpentinized olivine, and amphibole,

with the olivine becoming increasingly ferrous. According to A. Kahma, the hybridization began there at the end of the solidification period for diabase. In other instances, the proximity of a roof undoubtedly stimulated the formation of acid segregations in diabase (trap) bodies but the roof material did not directly affect their composition. Thus, according to P. Hotz [21], the upper parts of Triassic diabase sills of Pennsylvania carry diabase pegmatite and lenticular granophyre bodies. He explains their formation by the fact that, in the crystallization of magma in the upper part of a sill, residual fluid was accumulated there, with a concentration of iron, alkali, silica and water, which was responsible for the acid rocks. This view still leaves unexplained the origin of different rocks -- diabase, pegmatite and granophyre -- under the same conditions and in the same way. The author's concept of the exclusive part played by fractional crystallization does not fully explain the picture as we know it, unless the hybridism processes are taken into consideration.

In explaining the origin of some micropegmatite or diorite from basic intrusive blocks, it should be kept in mind, however, that these blocks, despite their obvious hybrid origin, are not in direct contact with the country rocks. Blocks of a perfectly similar composition may be said to exist independently of the lateral intrusive rock of the area. Such blocks may be represented by sandstone, argillite, tuff, limestone, granite, etc., as witness the Sos'va River differentiated diabase-monzonite intrusions studied by this author in the northern Urals [5], certain sills of the Tungus traps [4, 6], etc. An interpretation of the origin of these bodies is possible only through deep assimilation or else through contamination of the sial country rock by basic magma, at depth or during the magma's journey to the surface. The possibility of such processes is confirmed by the considerably higher temperatures in deeper parts of the magmatic column, as compared with the magma temperatures at the place of its solidification.

A solution of our problem calls for a comprehensive knowledge of the substratum underlying the trap deposits of the upper structural stage. It may be assumed that a number of metallogenic features of basic, basalt and similar formations, too, will find an explanation in our full understanding of the deep contamination processes in basement rocks which carry various ore components, either dispersed or concentrated ([4] as applied to Siberian traps). This very important problem deserves special study.

SUMMARY

Without pausing here for other interesting problems of origin and evolution of magma, we shall set forth some general conclusions arrived at on the basis of an analysis and correlation of the above material.

1. The origin of basaltic magma or magmas is related to definite deep geospheres of both basalt and peridotite composition. These geospheres are most likely to be in a solid or vitreous state and have a somewhat variable composition.

2. Basalt magma surges periodically in the earth's crust. Because of the original lack of homogeneity in the substratum, the nascent molten masses may be of a somewhat different composition, in the general vicinity of an "average" basalt magma.

3. Basalt magma penetrates the upper levels of the crust in a liquid state. Its further evolution depends first on structural features of these upper levels, different for the platform, orogenic, and other provinces; second, it depends on the tectonic conditions of that segment of the crust at the time of arrival and solidification of the magma.

4. It is in these upper structural levels that basalt magma undergoes its greatest changes (differentiation, crystallization), as a result of abrupt changes in temperature and pressure and in the composition of the enclosing rocks in contact with the magma.

5. The evolution of basalt magma proceeds along several lines, all leading to the formation of alkaline, sub-alkaline, acid, or pegmatoid derivatives. A particular course of this evolution is determined by both the original composition of a given magma and by some of the above-named factors.

6. The Kennedy-Anderson hypothesis [25] of but two initial types of basalt magma, even as complemented and somewhat modified by their successors, does not explain the multiplicity of natural phenomena.

7. The phenomena of assimilation, in a broad interpretation of this term, are most important in the process of formation of basalt magma itself as well as of various derivative rocks. Distinction should be made between the processes of deep assimilation (contamination) and local assimilation or hybridism.

8. Intrusions of orogenic zones, of the lower structural stage (basement) of a platform, and of its upper stratified zone should be distinguished within the group of hypabyssal (trap) basalts.

9. Metallogenic features of a basalt magma are closely dependent on the composition of both the magma and the enclosing substratum, as well as to the further progress of the magma's crystallization and differentiation.

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MELANOCRATIC ROCKS IN CERTAIN REGIONS OF THE U.S.S.R.

by

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This paper is an attempt to clarify and refine the present ideas on melanocratic vein rocks associated with intrusive granitoids, often but not always assigned to lamprophyres.

* * * * *

GENERAL REMARKS ON LAMPROPHYRES

Lamprophyres, so named by Gumbel, are one of the most ambiguous rock groups, in terms of the variety of their petrographic types, their occurrence and their origin.

A comparatively simple and logical definition was proposed by G. Rosenbush who assigned them to the vein rock group, diaschistic schizolite subgroup.

One cannot but agree with Rosenbush's qualification of the term, "lamprophyre," namely, that geologically and genetically lamprophyres are not independent formations but closely related to proximate deep-seated rocks.

Another characteristic feature of lamprophyres is that they are melanocratic vein rocks with granular or porphyritic texture. It follows that the rocks which fill up the conduit vents of extrusive formations should not be regarded as lamprophyres.

As pointed out by B. M. Kupletskiy [13], variations in the mineralogic composition of lamprophyres have led to an abundance of specific terms. Their chemical composition is also very unstable. Consequently, Berger's attempt (1923) at differentiating the lamprophyres by their chemical composition was unsuccessful.

It should be added that many a work on melanocratic vein rocks fails to give, for one reason or another, the complete petrographicide-description of such rocks and their contacts. The authors limit themselves to assigning a new name to the rock under study, which conceals its true nature and its relationship to the enclosing rocks.

Finally, a lack of precision in the terminology must be noted, along with the absence of definite boundaries between rock groups with special names.

All this is easily explained. Based solely upon mineralogic or chemical composition, our nomenclature does not reflect the genetic classification of rocks. It is natural, then, that rocks petrographically similar but genetically different will possess specific properties broadening their petrographic groups.

Considering the inaccurate grouping of rocks of different age and origin (plutonic dikes, roots of extrusives), the complex character of the lamprophyre problem -- that of a rock group arbitrarily contracted or expanded by different authors -- is quite obvious.

A valuable attempt at a quantitative mineralogic classification was made by B. M. Kupletskiy. On the basis of previous work, he recognizes three branches of lamprophyric rocks: 1) dolerite (spessartite, kersantite); 2) syenite (vogesite and minette); and 3) alkaline lamprophyres.

In the last decade, the term, "lamprophyres", has gradually lost its independent and definite meaning, and its usefulness with it. Still, lamprophyres are treated in a number of works, althouth without much emphasis.

Specifically, the paper by O. S. Polkvoy [19] on the formation of acid intrusive vein rocks, based on the study of 29 intrusive granitoids of Central Kazakhstan, mentions associated spessartites of a single intrusion. At the same time, the so-called second-stage vein rocks, both intermediate and basic, occur in nearly every complex. Since Polkvoy's paper contains no qualitative data on the petrographic and chemical composition of these second-stage vein rocks, the difference between gabbro-diorite, micro-diorite and diorite porphyrite, on one hand, and spessartite on the other, remains obscure.

In his recent monograph on dikes, Kh. M. Abdullayev [1] devotes but a few pages to "lamprophyres," obviously regarding them

(without saying so) as a composite group without any strict petrographic meaning. Such a treatment of lamprophyres by Kh. M. Abdullayev is in contrast to his much more voluminous chapters on dikes of the basic, ultrabasic and alkaline groups.

Kh. M. Abdullayev cites a fairly large number of analyses of diabase and porphyrite making up the Akuraminskiy range dikes (central Asia). It should be noted that the analyses of many varieties of diabase rocks of that region are not distinguishable from those characterizing the diorite branch of lamprophyres: spesserites and kersantites. On the other hand, his table of chemical analyses exposes the lack of precision in the present nomenclature and classification of dikes. Thus, the diabase and diabase porphyrite group includes rocks with a 43% 54% SiO_2 content and 2% to over 6% of alkali. Incidentally, the sum of component oxides in the chemical analysis of a diabase porphyrite (specimen 307, page 88) comes to 104.44%, with 103.05% for specimen 671 ([1], page 89).

Even disregarding this last circumstance, it may be stated that the names assigned by different authors to melanocratic vein rocks are oftentimes rather arbitrary and give no basis for guessing at the composition of such rocks.

The origin of melanocritic dike rocks associated with granitoid intrusions has not been interpreted in an acceptable manner.

Most petrographers believe with Smith (1936) that Rosenbush's concept that aplites and lamprophyres are complementary rocks originating in the residual liquor after the granite magma has crystallized is hardly valid for a magma which has attained the granite stage of evolution. Many petrographers (A.N. Zavaritskiy, B.M. Kupletskiy and others) believe that all attempts at an explanation of the origin of granite lamprophyres must account for hybridism and assimilation. However, the significance of these phenomena in the formation of lamprophyres has practically not been considered in specific studies.

Of interest is A.N. Zavaritskiy's concept [9] of the Ray-Iz massif schizolites. In his opinion, they were formed out of residual magmatic solutions of a near plagioaplite and pegmatite composition but hybridized in reactions with the massif's rocks (paulopost hybridism), to produce a series of vein rocks diversified in composition.

Zavaritskiy's paper [8] on the Magnitnaya Mountain lamprophyres contains some extremely interesting observations. In noting the similarity between the diorite and porphyrite dikes in the ore-bearing sequence of the Magnitnaya and a recently found lamprophyric dike cutting the granites, as well as the complexity of their alterations, he believes that pneumatolytic metamorphism of the granite intrusion continued for a long time after that event and occurred in deeper portions of the granites.

E. Raguin [25], citing a number of views on the origin of lamprophyres, in the second edition of his monograph, Geology of Granite, definitely regards them as magmatic rocks. He cites Van Bemmelen's opinion, based on observations of Neogene granites of Java, that they were formed within an activated surface contact zone of metasomatic Neogene granite and then injected into the fissures of nascent granite. Arribas San Miguel [24] concluded on the basis of his study of lamprophyres (spessartites, camptonites) of the Costa Brava (Spain) granite massif, that these veins were basalt dikes, intruded prior to the granitization which was responsible for the granites.

In his work on the Tur'inskiy skarn site, D.S. Korzhinskiy [10] divides his vein series into pre-skarn and diabase porphyrites. According to him, the porphyrites were formed either during or after the skarn-making process, although their relationship with the ore is not quite clear. He also notes the presence of rare plagioaplites, in one place definitely cutting the skarns.

In recent years, petrographers studying in Kazakhstan -- O.S. Polkvoy, V.S. Koptev-Dvornikov and V.K. Monich -- undertook a study of the formation of vein series accompanying the granite intrusions. The elegant concept of these authors on the direction of evolution of granite magma, leading to a two-stage formation of vein rocks accompanying the granite intrusions, and explaining the position of the ore-making process in the course of this evolution, is not without serious contradictions. It needs additional work and a detailed explanation of the formation of a long sequence of differentiates within a deep-seated granite magma.

The works of O.S. Polkvoy and V.S. Koptev-Dvornikov deal with vein rocks of granitic intrusions. In that case, it is natural to distinguish two or more formational stages for the derivatives of a magma responsible for this intrusion and its vein rocks. However, it follows from the concepts of O.S. Polkvoy and V.S. Koptev-Dvornikov that the evolution of a granite magma responsible for the given intrusive granite complex is not terminated with crystallization of the residual magma, the most eutectic and comparatively low-temperature mixture, in the form of pegmatites, aplites and high-

emperature quartz veins. It appears that hese granitic intrusions generate a new second) stage of vein derivatives, partly basic rocks whose magma had a tempera- ure higher than the aplite and quartz veins. At the same time, the authors in effect asso- iate these second-stage vein rocks with a lifferent magmatic source, deeper than the granitoids which contain them.

Second-stage vein rocks are emplaced in consolidated granite intrusion, with the ormation of tempered zones at their fringes. n this interpretation of second-stage vein rocks, a vein series associated with a granite ntrusion can never be split according to the ormational stages of the emplacing granite body. Insofar as they have a different source, they naturally must be considered ndependent of the granite intrusion from which, in addition, they may be separated by a long time interval.

In noting the identity of the second-stage likes for all Devonian and upper Paleozoic ntrusions of central Kazakhstan, O.S. Polk- voy supposes that this suggests a common hearth (or hearths) for that entire vast ter- itory and, more specifically, that the course of differentiation in these dikes was regulated by similar conditions of tempera- ure and pressure.

O.S. Polkvoy has calculated that areas of vein magma constitute as much as 3% of he area of the host intrusions. At the same ime, the ore deposits are found to be gen- etically related to the second-stage vein rocks. This premise leads to the logical con- clusion on the lack of genetic ties between ore-making and granite intrusions but demonstrates genetic ties with deep-seated sources whose harbingers are the second- stage vein rocks.

Unfortunately, the petrographic relation- ships between the second-stage vein rocks and different intrusive phases of the granite complex is not dealt with in any detail, either in the Polkvoy work or in Koptev- Dvornikov's papers [11, 12] or even in Monich's substantial monograph [15]. More specifically -- and this is especially impor- tant -- these works contain no detailed treatment of the composition of vein rocks and of contact phenomena in those rare in- stances where they are cut by alaskite gran- ite and pegmatite (usually at a late stage of granite intrusion).

Both laboratory data and personal observa- tions of granite intrusions in different regions reveal that melanocratic vein rocks, mor- phologically discrete but complex in their composition, associated with granite intru- sive bodies of a complex composition, and near to it in age, do not occur in alaskite rocks which usually occur during formation of granitoid intrusions.

All of this leads to a belief that the origin of assorted vein rocks associated with granite intrusions, the sequence of their formation, their position and that of the ore-making process in the course of the emplacement of granite intrusions, find no logical explanation in the concept of splitting of the vein process into two stages, in the sense implied by O.S. Polkvoy and V.S. Koptev-Dvornikov.

Interesting but contradictory material on vein rocks is presented in the Izvestiya of the Academy of Sciences, U.S.S.R., Geological Series, No. 1, 1957 [7, 17, 18, 22].

Unfortunately, most of the authors did not treat the genesis of vein rocks as a whole in terms of their relationship to the ore-making process, with the aim of understanding the entire course of the evolution of magma which results in granitoid complexes, the dike series, and in formation of ore. As a consequence, some of the readers may conclude on the basis of this material that there is no definite pattern and sequence in the relationship between the magmatic and ore-making processes.

The evidence presented is equally convincing as to the dikes being pre-ore, inter-ore or post-ore magmatic formations. Such a vagueness, in our opinion, is due chiefly to a deficiency in material. This, in turn, may be due to the lack of a correct interpretation of the existing data.

Unfortunately, there still is no comprehensive scheme of development of magmatic complexes, compiled on the basis of specific cases, which would graphically illustrate the sequence of magmatic formations in time and space. The complex character of many intrusive processes, their multiphase aspect, as well as the pegmatitic and aplitic processes, and different petrographic types of melanocratic dikes and different genetic types of ore-making are well known.

M.A. Favorskaya [22] has shown fairly well the evolution of the South Primor'ye (Maritime Region) magma which produced granite intrusions accompanied by spessartites and later gray aplite. Ore-bearing skarns (containing tin and magnetite) preceded the red aplites which are derivatives of alaskite intrusions. However, the granite-porphyry and felsite dikes and stocks, which are associates of polymetallic ore deposits, are separated from the ore veins by pre-ore porphyrite dikes; in the post-ore period they penetrate the diorite porphyrites and

gabbro porphyrites.

Unfortunately, the paper, as well as the preceding monograph by M. A. Favorskaya, do not describe the contacts and the overall composition of these formations. There is no certainty, therefore, that they reflect evolution from a common magma, rather than a complex and unrelated picture.

Such a complex evolutionary picture of magmatic and ore formations is shown in a comprehensive paper by I. F. Grigor'yev and Ye. I. Dolomanova [7]. According to the authors' data, dikes of both groups (i. e., including the second-stage dikes of V.S. Koptev-Dvornikov, O.S. Polkvoy, and V.K. Monich) are pre-ore in origin. It is of interest that a portion of second-group dikes (spessartites and diorite porphyries) was intruded prior to the tin-bearing granite. According to the authors, dikes of a similar type were formed after the tin-bearing granite, but prior to the associated ore-making process. The authors are not inclined to connect the Budyumkanskiy diorite-porphyrite dikes with the ore-making tectonic and magmatic cycle.

O.P. Polyakova [18] has determined the pre-ore date for lamprophyres (spessartites and kersantites) of the Kadainskiy polymetallic ore deposit. V.S. Kormilitsin [10-a] believes the kersantites of that locality to be post-ore.

M. M. Povilaytis [17] described in some detail the ore-making process of the Dzhidinskiy deposit; specifically, she confirmed its pulsating character. She did not consider, however, the possibility of a renewal of the ore-making process, brought about by the superimposed action of an essentially alkaline magma which produced the so-called "kersantites."

The term, "kersantite," has something of a hypnotic effect on the reader, kersantite being a lamprophyre, and lamprophyres generally being related to the deep-seated rock enclosing them. Thence, a logical conclusion of the multiple aspect of magma- and ore-formation.

At the same time, the Povilaytis description of "kersantite" (the sum of alkalies reaches 11%, with 6.07% of K_2O) does not fit the composition of such rocks. With this alkali content and with 2.70% CaO and 2.36% MgO, a rock cannot be purely biotite-plagioclase in its mineral composition. It undoubtedly contains potassium feldspar and is nearer the trachitoid type. On these grounds, it is relegated to the derivatives of a different and younger type.

D.K. Akhmerov and N.V. Mayorov [5] cite some interesting facts on vein rocks of the Chinarsaysk granodiorite intrusive (of the Zeravshan range). Their treatment of the genesis of vein rocks would be quite convincing if they had cited straight facts proving the intrusive sequence of vein rocks and had paid more attention to the study of contact phenomena. The sequence of granodiorite intrusion -- lamprophyres -- aplites -- may be explained, just as the authors believe, by fractional crystallization of the residual magmatic solution, if the geologic data warrant it and consideration is given to the relatively low temperature of the aplite residue solution as compared with lamprophyre magma.

Field data on the evolution of magmatism in individual fold provinces demonstrate the recurrence of magmatic pulses throughout geologic history, accompanied by the formation of assorted magmatic complexes of different ages, with all of their derivatives.

We have no grounds for isolating dike rocks (both melanocratic and leucocratic) from other magmatic phenomena, if we want to determine the interrelationships between rocks and ores in all their diversity.

Only the total data establishing a "kinship" or "comagmatism" -- i.e., a common origin of an intrusion, a vein rock and an ore -- will give a clear solution to the problem of the interrelationship of these formations within an intrusive complex. The criteria of this "kinship," previously set forth by this author [2], are as follows: 1) territorial and geologic connection; 2) similarity in age and degree of metamorphism; 3) textural and structural features in common pointing to a deep-seated environment of genesis of rocks and ores; 4) geochemical features of plutonic and vein rocks, as reflected in the associated ore formations.

Without such analysis, a differentiation of magmatic associations in numerous intrusive rocks and associated dike formations is very difficult. There is always the danger of combining into a single genetic series, independent formations clearly different in age and having quite different magmatic origins.

The determination of comagmatism of vein rocks and the granitoids which they cut should be based on the following premises:

1. Both the intrusive rocks and vein derivatives, being the components of a discrete evolutionary process of a magmatic source, must be closely associated in time, i.e., contemporaneous within the error of determination of geologic time.

2. Proximity in time determines similar-

ity of the sedimentary environment, which in turn brings about a similarity in the degree of crystallization of vein rocks.

In many instances, true melanocratic vein rocks change to an extrusive-like variety only within a narrow contact fringe, which suggests a temperature difference at the boundary between the intruding vein magma and the emplacing rock. Since this contact metamorphic zone is very thin, locally altogether lacking, the temperature difference at the contact evidently was not great and probably disappeared rather quickly.

Pegmatite, aplite and granite, within a granitoid complex, are usually regarded as derivatives of the same magma. It is natural that, if melanocratic vein rocks are caught between intrusive and associated vein rocks, these melanocratic rocks, too, must be regarded as comagmates, unless, of course, there is evidence of their connection with a granite intrusion of a different geologic age.

In their structure, granitoid complexes may be divided into two main types, as follows:

1. Petrographically homogeneous complexes made up of granitoids of the same type, such as granodiorite or alaskite. Massifs of this type are usually a result of a single magmatic intrusion, with a subsequent evolution of the magma and its derivatives, in situ.

2. Morphologically discrete bodies of complex composition, carrying a definite proportion of quartz diorite, granodiorite, granite both uniformly grained and porphyritic, alaskite, etc.

This type of granitoid intrusion is usually multiphase, with a metasomatic stage superimposed, as a rule. A great number of studies demonstrate that vein rocks -- both melanocratic and aplitic -- are comagmatic with granodiorite granitoids. Comagmatic melanocratic vein rocks are lacking, as a rule, in alaskite granite; aplite and pegmatite, on the other hand, are common.

SOME RESULTS OF THE STUDY OF MELANOCRATIC VEIN ROCKS IN THE U. S. S. R.

Northern Caucasus

The author has published several papers on the development of magmatic activity in the Northern Caucasus and its manifestations in different structural zones of this region. Only now, however, does a tentative classification of its vein intrusives become possible on the basis of comparative study of their magmatic complexes.

The distribution of melanocratic vein rocks in structural zones of the Northern Caucasus is extremely uneven. An idea of it is given below.

I. Axial Zone of the Main Range

Ancient complexes of the axial zone are pierced by minor upper Paleozoic intrusions. In individual sections associated with transverse structures, the intrusions are represented by Cenozoic granitoids commonly occurring with Tertiary and Quaternary massifs. Dikes of melanocratic rocks are well developed along the entire axial zone (about 800 km); they usually trend northwest. Their petrography has been studied but little; most of them are generally regarded as post-Jurassic diabase.

Initial comparative petrographic study of the axial zone reveals that the term, "diabase," disguises diverse melanocratic rocks differing in petrographic composition and genesis.

As a rule, leucocratic vein rocks (aplite, pegmatite) are associated in all structural zones with granitoids of all ages. Accordingly, we shall direct our attention chiefly to melanocratic dikes.

Three geologic groups are tentatively recognized among the multitude of dike rocks of the axial zone.

1. Hornblende gabbroids, uncommonly with pyroxene, forming a lamprophyre (spessartite) series of lower Paleozoic plagiogranodiorite intrusions. They are typical of the Dar'yal, Kassar and Aksaut granitoid complexes, granitized ancient sequences at the Klukhor pass, and metamorphic schists in the axial interfluves between the upper courses of the Laba and Belaya.

2. Intensely alkaline gabbroids with a common pyroxene (titanaugite) which generally becomes the predominant rock-forming component. Dikes of these rocks cut Lower Permian and Lower Jurassic sediments of the neighboring structural zones. Here belong the albite diabase of Krasnaya Polyana, described by D. S. Belyankin.

3. Mesozoic and Cenozoic formations of the western part, and those close to the Kazbek volcanic area (eastern part), all cut by dikes of diabase porphyrite and highly alkaline rocks, as well as by andesite,

basalt, and liparite [rhyolite] dikes related to Tertiary-Quaternary volcanism.

II. Granite Zone of the Main Range

All along this zone, rocks at the top of granite intrusions contain dikes of metamorphosed gabbroids, analogous to the hornblende spessartite of the axial zone. An amazing feature of the Main Range granite complexes is their extreme paucity in dikes of melanocratic vein rocks. The dikes occurring there are represented essentially by two rock types -- pyroxene gabbroids (with titanaugite) with higher sodium content and by plagioclase porphyrites having a Cenozoic aspect.

Granodiorites of the complex Aksaut-Mark complexes contain large xenoliths of dioritic rocks, petrographically similar to the Urushten spessartite of the axial zone.

III. Zone of Longitudinal Depressions

Different sedimentary rocks are involved in the structure of this zone between the Ardon and Belaya rivers.

1. In its uplifted segment -- in the area of the Teberda River -- this zone is made up of Paleozoic rocks, with rare pyroxene gabbroid dikes (with titanaugite) cutting the Lower Permian deposits.

2. In the Baksan basin, the longitudinal depressed zone, and in part the Main Range granite zone bordering it on the south, are pierced by intrusions of porphyritic Tertiary granite which are cut by dikes of granosyenite porphyry, liparite (dellenite) and rarely by basic rocks of an andesite-basalt composition.

3. In the Fasnal' area, the longitudinal depressed zones of Lower Jurassic age are cut by dikes of quartz porphyry.

4. The Zakan syenite complexes are cut by rare veins of leucocratic rocks (rocks having oligoclase with a low microcline content).

IV. High Front Range Zone

In the area of exposure of crystalline basement rocks of this zone (the Urushten complex), comagmatic dike rocks, metasomatically metamorphosed at a late stage of evolution (Nametasomatism), are altered to the point of becoming amphibolites. Rare dikes of fresh melanocratic rocks are represented by pyroxene gabbroids analogous to those cutting the Lower Permian deposits of the longitudinal depressed zone.

Structural planes of this zone are marked by dikes of upper Paleozoic porphyries, and dikes of intensely alkaline pyroxene gabbroids (the pyroxene is titanaugite) occur in areas of Devonian phyllite (of Nikitina River basin, northern subzone). In the Kuban' basin, the basement and Jurassic rocks are cut by porphyrites and dikes of andesites and keratophyres (quartz-free). East of Malka River, in the Baksan, Chegem, Cherek basins, Cenozoic extrusives are present without the accompanying vein series.

This distribution of melanocratic vein rocks makes it possible to divide them into the following groups:

A. Melanocratic dikes associated with granitoid rocks, along with aplites and pegmatites:

1. Lamprophyre dikes (spessartite) of the Main Range axial zone, the Dar'yal, Kassar and other complexes, along with the majority of dikes in the Klukhor pass area. Age, early Paleozoic.

2. Dikes of Cenozoic leucocratic granodiorite-porphyries, liparites and plagiopyroxene occurring in places in intrusions of both the Main Range granite (Upper Paleozoic) and the Tertiary granite of Tyrny-Auz.

B. Dikes of regionally-developed melanocratic rocks.

1. Dikes of intensely alkaline pyroxene gabbroids (titanaugite). Post-Jurassic but probably pre-Upper Cretaceous.

2. Veins of Cenozoic-like plagioclase and pyroxene porphyrites of an andesite-basalt type, occurring in the Main Range granite and in the Tyrny-Auz Tertiary granite.

3. Highly alkaline dikes cutting the Mesozoic Cenozoic deposits of the western part of the Northern Caucasus.

In this paper, group A dikes are considered to be directly related to lamprophyres.

VEIN ROCKS ASSOCIATED WITH GRANITE INTRUSIONS OF DIFFERENT AGES

A. Vein Rocks in Plagiogranodiorite Lower Paleozoic Intrusions of the Axial Zone

A description of the geologic relationship and the composition of the complex rock

ssociations making up the Dar'yal, Kassar, nd Aksaut granitoid complexes in the east f Central Caucasus, is given by this author, lsewhere [3, 4].

Data from these papers suggests a com- lex process of formation of those granitoid omplexes. It has been shown that the ori- inal substratum -- Lower Paleozoic schist - was intruded by plagiogranodiorite accom- anied by a vein series of gabbroid rocks kin to spessartite and later by leucocratic ocks of a plagioalaskite and plagioaplite ype. Later on, in connection with a subse- uent magmatic cycle, the rocks of these omplexes underwent potassium metasoma- ism with an uneven development of potash eldspar.

A careful study of these rocks yields oluminous evidence of a later development f plagioalaskite and plagioaplite, as com- ared with vein gabbroids which cut the ranites of the complex.

Specifically, it has been shown that vein abbroids which "cut" the Dar'yal granite vere subject to the same K metasomatism. lere is a paradox: a vein is older than ne granite it cuts. However, a petrographic tudy of the contact and the absolute age ata provides this interpretation of the com- lex relationship.

Quite analogous vein gabbroids (spessar- ites) have been intruded into the enclosing ocks having contact haloes and into the top f these complexes. Similar complex rela- ionship between the "diabase" and micro- line granites are observed in the Klukhor ass area (Teberda).

In the western Caucasus, along the upper ourse of Malaya Laba, analogous vein rocks re abundantly developed in Lower Paleozoic chist and gneiss.

The chemical composition of these vein ocks and of some of the enclosing rocks is iven in Tables 1 and 2.

These analyses show that basic vein rocks ssociated with the Lower Paleozoic grani- oid complexes of the axial zone are chemi- ally fairly consistent. Only specimens 3/11 (Kassar gorge) and 864/40 (Aksaut) re somewhat richer in potassium and silica. his enrichment can be observed under the iicroscope: in specimen 864/40, later struc- ires of potash feldspar and biotite are super- nposed on the rock matrix and occur in iin veinlets in it.

A distinguishing feature of this rock roup, the predominance of Na_2O over K_2O, convincingly demonstrated in these anal- yses. It is particularly characteristic of the extremely acid vein rocks, as well (plagio- alaskite and aplite, specimens 217/55 and 221/55). An analysis of a vein (specimen 246/55) cutting a basic vein rock (specimen 247/55) definitely shows that it is a hybrid formed in plagioalaskite contaminated by a vein gabbroid (spessartite) which cuts it.

Analyses of specimens 259/55 (spessar- tite and phyllite) and 247/55 (spessartite in granitoids of the Dar'yal complex) reveal their practical identity, which points to the slight effect of assimilation in the formation of gabbroid vein rocks.

An attempt to determine the absolute age of most vein rocks by the K-Ar method was undertaken by the Dagestan Affiliated Branch of the Academy. The difficulty of such an attempt lies in the low potassium content in rocks. This brought about con- siderable variations in the results obtained by different laboratories. More consistent figures were obtained for leucocratic rocks.

A common figure, independently arrived at in different laboratories was accepted as the value of the potassium content. The rock age was estimated from the radiogenic argon content, an insignificant amount but definitely determinable by the mass- spectometric method. The geologic and petrographic evi- dence of an intrusion of plagioalaskite, after the spessartite, has been corroborated by the absolute-age data. The age range for the basic vein rocks is 300 to 350 million years, which is in full accord with their geologic position. The spessartites affected by K metamorphism (effect of late Paleozoic intrusions) have turned out to be of a younger age (Carboniferous -- Early Permian).

The general chemical properties of basic and acid vein rocks and of the nearly con- temporaneous granodiorite plutons which they cut -- along with the fact that vein gabbroids (spessartite) are caught in a "fork" between the granodiorites and plagioalaskites -- sug- gests that representatives of different petro- graphic types of this series are comagmatic. At the same time, the two vein rock types -- the gabbroids (spessartite) and plagio- alaskite -- are complementary and may be assumed to represent the differentiation pro- ducts of a residual plagiogranodiorite magma. These products -- banalite and tonalite -- are characteristic of the Urushten-type asso- ciation. Tables 1 and 2 give an analysis of a banalite-type plagiogranodiorite from the area of Malaya Laba, along with the average of two analyses of complementary rocks (specimens 217 and 247).

This conclusion became possible only after the true relationship of leucocratic and

Table 1

Chemical Analyses of Vein Rocks Associated with Granites of the Axial Zone

Oxides	Vein gabbroids (spessartite): Specimen 259/55 in phyllite	Vein gabbroids (spessartite): Specimen 247/55 in cryst. rocks	Hybrid rock specimen 246/55	Plagioaplite specimen 217/55	Plagioaplite specimen 221/55	Kassar gorge specimen 68/11	Arsaut, specimen 864	Malaya Laba specimen 594/45	Analysis $\frac{259 + 217}{2}$
SiO_2	47,89	48,72	59,02	78,25	—	48,13	59,36	—	63,07
TiO_2	2,16	1,96	0,55	0,04	—	1,14	0,50	—	1,10
Al_2O_3	15,60	15,88	18,74	12,94	—	17,10	17,59	—	14,27
Fe_2O_3	0,75	1,03	0,29	0,04	—	1,38	2,33	—	0,40
FeO	11,87	9,25	4,16	0,35	—	8,43	3,57	—	6,12
MnO	0,30	0,21	0,11	Сл.	—	0,13	0,14	—	0,16
MgO	6,54	6,59	3,03	0,06	—	8,07	3,22	—	3,30
CaO	9,32	11,20	7,66	2,24	—	11,48	5,76	—	5,78
Na_2O	2,87	2,68	5,49	5,70	5,48	1,93	3,30	2,90	4,28
K_2O	0,14	0,42	0,33	0,17	0,40	1,08	2,32	1,17	0,15
H_2O^-	0,08	0,10	0,04	0,04	—	0,06	Not det.	—	—
H_2O^+	1,73	0,55	0,26	0,05	—	1,04	1,70	—	—
P_2O_5	0,27	0,23	0,13	0,02	—	—	0,15	—	—
CO_2	0,20	0,30	—	—	—	—	—	—	—
Sum	99,72	99,12	99,76	99,79	—	99,97	99,99	—	—
Ra 10^{-10}	Not det.	0,9	—	—	1,7	—	—	—	
Th 10^{-4}	»	8	—	—	16	—	—	—	
U 10^{-4}	»	3	—	—	5	—	—	—	
h	98	92	97	98	95	72	70	78	
r	Not det.	70	—	—	80	—	—	—	
Age according to K-AR meters	300	340	250	235	240	—	180	210	

Note: Comma represents decimal point.

melanocratic rocks had been established, viz., that this differentiated complex was subsequently affected by the late Paleozoic and Mesozoic magmatic processes which unevenly altered the Dar'yal complex to porphyritic (porphyroblast) microclinized granite.

It is pertinent to cite the data on residual magnetism in some of the rocks of the Northern Caucasus. They were obtained at the author's request by A.G. Komarov.

The rocks selected are representative of the Caledonian (Urushten) complex, but have a different history, as follows:

1) Microclinized granodiorite and plagio-alaskite of the Dar'yal complex and associated dikes of basic rocks;

2) Plagiogranodiorite pebbles in the Lower Devonian (?) conglomerates along the Nikitina River (Malaya Laba);

3) Plagiogranite of the Bol'shiye range, not affected by younger granite intrusions.

The results of this study are given in Table 3.

In his summary of March 28, 1956, i.e., at the time of publication of my paper [3] on the relationship of the Dar'yal granites and their intrusive vein rock, A.G. Komarov had this to say:

"A correlation of these two tables giving data on the Uralian Caledonian complex shows that the data obtained in all instances point to nearly contemporaneous rocks, chiefly pre-Devonian and most likely Silurian." And again, "It may be assumed with reservations that the Dar'yal gorge granitoids are younger than the other rocks, lying somewhere on the Caledonian-Hercinian boundary."

The results of study of magnetism in the Caucasian rocks by A.G. Komarov have shown that geologists must not overlook this natural phenomenon. Komarov's conclusions are in accord with the geologic and petro-

Table 2

Computations of Analyses in Table 1
(After A.N. Zavaritskiy)

	Spec. 259/55	Spec. 247/55	Spec. 246/55	Spec. 217/55	Spec. 68/11	Spec. 864/40	Spec. $\frac{259+217}{2}$	Spec. 6/40
S	57,8	58,0	68,5	84,8	56,4	70,5	71,8	71,1
a	6,7	6,7	12,7	12,1	6,0	10,8	9,4	12,1
c	7,4	7,5	6,3	2,1	8,6	7,0	4,7	2,8
b	28,1	27,8	12,6	1,0	29,0	11,4	14,0	14,0
f'	44	36	35	46	32	48	44	51
m'	41	41	40	13	48	48	40	33
C'	15	23	24	40	19	2	15	15
n	98	92	97	98	72	70	98	98
t'	3,2	3	0,7	—	1,5	0,5	1,3	0,9
φ	2	3	2	13	4	17	3	26
Q	— 5	— 5	+ 5	+43	— 8	+12,7	+20	+16

Specimen 259/55. Vein gabbroid (amphibole-plagioclase spessartite): the Terek, above Lars settlement; cuts phyllite; analyst, N.V. Voronkova.

Specimen 247/55. Ditto, cutting the Dar'yal complex granitoids; analyst, N.V. Voronkova.

Specimen 246/55. Hybridized plagioalaskite cutting spessartite; analyst N.V. Voronkova.

Specimen 217/55. Plagioaplite cutting the Dar'yal complex granitoids.

Specimen 68/11. Vein gabbroid (spessartite of the Kassar gorge, slightly altered through superimposed metasomatism.

Specimen 864/40. Ditto, in greenstone rocks of the Aksaut complex; altered through late Paleozoic K metasomatism; V.M. Nekrasova, analyst.

Specimen 594/45. Amphibole-plagioclase spessartite in metamorphic schists; upper course of the Malaya Laba.

Specimen 6/40. Gneissic plagiogranodiorite (banatite) of the Malo-Labinskiy complex (Urushta complex; [2]).

Table 3

Specimen No.	Locality	10^{-6} (magnetic susceptibility)	$I_r\ 10^6$ (residual magnetism)	I_r/I_i
221	Dar'yal complex, plagiogranitogneiss	31	8.6	0.55
262	Microcline granite, same locality	11	3.1	0.56
245	Vein spessartite, same locality	92	15.0	0.33
47	Bol'shiye Balkany, plagiogranite	308	41.6	0.27
48	Ditto	30	5.0	0.33
91/55	Nikitina River, D_1 plagiogranite boulder	17	2.3	0.27
421/52	Same locality	35	6.6	0.38

graphic data on magmatism of Northern Caucasus. Only one correction is warranted: the large I_r/I_i ratio for the Dar'yal granitoids is due not to their comparative youth but rather to the complex evolution they underwent as a result of superimposed younger (upper Paleozoic and Mesozoic) magmatic processes.

B. Dikes in Microcline Granites of the Main Range

Leucocratic derivatives such as pegma-

tites and aplites genetically related to each of the granitoid groups which form a consecutive series, granodiorite-granite-alaskite, are widely developed among the Main Ridge granitoids (the granite zone).

Melanocratic dikes of basic rocks are rare in the Main Range granitoids. They occur in granites along the Malaya Laba (Rastayka and Bezymyannaya rivers and a left near-delta tributary of the Tsakhvoa River). Isolated dioritic rocks are, in rare instances, found in microcline granite. Petrographically, these melanocratic rocks (e.g., in the Marka River granite) are similar to spessartite dikes in the older Urushten plagiogranite.

The abundant "dikes" in microcline granite of the upper Teberda River are essentially the relicts of old vein formations in a metamorphosed (microclinized) formation top.

Another apparent contradiction -- diabase dikes obviously cutting younger granite -- is explained in the same way as has been done by the author for the Dar'yel complex, in 1956 [3], and by Arribas San Miguel [24] for the Costa Brava lamprophyres.

Dikes, younger than the Main range Upper Paleozoic granitoids, are represented by two petrographic types.

1. Gabbro rocks of the essexite type, with a high alkaline (sodium) content, occurring as dikes in both the upper Paleozoic granites and among much younger rocks (Permian and Lower Jurassic).

2. Fresh-looking Cenozoic-like plagioclase porphyries of the andesite-basalt and diabase type.

Rocks of type one are truly crystalline, have a regional distribution, and probably are genetically related to basic intrusions typical of the Trans-Caucasian Mesozoic-Cenozoic geosyncline.

Judging from their petrographic composition and geologic position, the North Caucasian manifestations of this stage of Jurassic magmatism are the basic hypabyssal intrusions changing to sheet flows of porphyrites typical of the Kuban'-Teberda-Eshkakon watershed, and especially well-developed near Karachayevsk.

Outstanding in its characteristics is a dike of intrusive pyroxene-plagioclase gabbroid (the pyroxene is titanaugite), which cuts muscovite granite (age, 230-240 million years) of the Eshkakon granite complex.

The absolute age of Karachayevsk andesite was found to be 120 million years. This gives credence to the absolute age determination scale, because the stratigraphic position of these extrusives is precisely established by the fact that they cut the Toarcian (Lower Lias) beds and underwent erosion in Aalenian (Dogger) time.

It follows that a large group of vein rocks of specific petrographic properties, and cutting sediments of different ages, may also cut the lower and upper Paleozoic Main Range granitoids, without being their comagmatic series. Instead, they are genetically connected with the extrusive series of basic (gabbroid) Mesozoic and Cenozoic rocks of higher alkalinity, which represents the intensive development of geosynclinal magmatism in TransCaucasia.

As previously mentioned, the upper Paleozoic Main Range granitoids are cut in the axial part of the range (in the region of Tsakhvoa River -- the Malaya Laba basin) by veins of dense Cenozoic-like plagioporphyrite representing the roots of a pluton considerably younger than the upper Paleozoic granite. These veins occur only in the vicinity of structural surfaces in shattered granite and are petrographically identical to dikes which are the roots of Cenozoic basaltoids of this part of the Caucasus. Tables 4 and 5 give the petrographic analyses of these rocks.

These gabbroids are externally dense, dark green to black, and are truly crystalline. They are ophitic in texture, changing to a finer-grained texture at the contact with enclosing rocks (microcline granite, Lower Jurassic deposits), with a vitreous contact metamorphic crust, 3 to 4 mm thick. Porphyritic texture becomes definite in the peripheral zone.

Their mineral composition: $Pl_{40-50}An$, monoclinic pyroxene (titanaugite), chlorite and serpentine (partly on olivine), titanomagnetite, occasional alkaline hornblende, apatite and prehnite.

Microcline granite in contact with a dike is shattered and greatly affected by it (i.e., by prehnitization, chloritization and carbonatization of the near-contact granite).

Plagioclase porphyrite which cuts the microcline granite at the mouth of the Tsakhvoa River is a dense black rock penetrating the shattered granite. Petrographically it is analogous to the andesite-basalts cutting the Tertiary El'dzhurtin granite (Tyrna-Auz).

There is no specific chemical composition typical of these vein rocks of the Main Range.

Table 4

Chemical Analyses of Vein Rocks Associated with Mesozoic and Cenozoic Granitoids

Components	Post-Lower Jurassic gabbroid dikes of Northern Caucasus		Dikes in the Tyrna-Auz Granites			Dike rock in the area of Gekharot intrusion (Armenia)	Specimen 379/55
	Specimen 179/56	Augite-diabase from Krasnaya Polyana	Granosyenite porphyry, specimen 341/56	Andesite-basalt, specimen 263/54	Dellenite		
SiO_2	48,71	47,15	68,29	47,67	70,84	53,02	50,42
TiO_2	1,70	1,32	0,51	1,12	0,41	1,33	1,48
Al_2O_3	16,19	16,09	15,02	14,54	14,76	17.28	17,52
Fe_2O_3	2,38	4,59	0,61	3,68	1,42	3,03	2,88
FeO	6,76	9,49	2,56	3,74	1,54	4,45	5,04
MnO	0,17	0,23	0.05	0,16	0,02	0,11	0,15
MgO	5,96	4,43	1,07	6,85	0.88	5,20	5,18
CaO	9,66	8,86	1,26	9,62	1,52	7,10	8,45
Na_2O	4,22	4,46	4,75	3,09	3,55	5,50	3,50
K_2O	0,71	0,39	4,15	2.12	3,12	1.42	1,14
BaO	—	—	—	—	—	None	None
Loss on ignition	2,65	2,39	1,05	1,74	1,42	1,76	4,46
H_2O	0,35	0,29	0,24	1,78	0,44	—	—
P_2O_5	0,24	—	0,20	0,84	0,25	0,32	0,25
Sum	99,70	99.69	99,76	CO_2 3.24	—	100,52	100,47
$Ra \cdot 10^{-10}$	0,5	--	2,7	1,0	—	4,8	2,1
$U \cdot 10^{-4}$	1,5	—	8,0	3,0	—	14,1	6,2
$Th \cdot 10^{-4}$	8	--	13,0	4,0	—	9	6
h	91	95	62	70	63	—	82
r	84	—	62	60	—	40	50

Note: Comma represents decimal point.

Table 5

Computation of Chemical Analyses of Vein Rocks Associated with Mesozoic and Cenozoic Rocks

	Specimen 179/56	Augite-diabase Krasnaya Polyana	Specimen 341/56	Specimen 363/54	Dellenites	Specimen 279/55
S	58,1	57,6	72,6	58.2	83	62,2
a	10,5	11,1	15,4	10,4	12,6	9,8
c	5,9	5.8	1,4	5,0	1,9	6,1
b	25,4	25,4	10,6	26,6	9,0	22,0
h	91	95	62.0	70,0	63.0	82,0
Q	—10	—13	+ 13	9.6	+33	- 1,4
f'	35	46	26	27	30	35
m'	40	31	16	46	17	47
c'	25	22	—	27		22
t'	2,5	2	0,5	1,7	0,4	2,4
φ	8	8	5,0	12	14	11
a'	—	—	57,0	—	51	—

The geologic position of veins which cut the microcline granite is such as to preclude their comagmatism with the granite, inasmuch as they represent subsequent magmatic cycles (Early Jurassic and late Tertiary -- early Quaternary).

C. Vein Rocks in the Tertiary Ėl'dzhurtin Granite of Tyrna-Auz

The Tyrna-Auz granite (El'dzhurtin) carry rare veins of aplite (composition: anorthoclase, oligoclase and quartz) and isolated veins of granosyenite porphyry, andesite-basalt and liparite-dellenites. The last two types of vein rock are considerably younger than the granites; they represent the roots of post-Tertiary -- early Quaternary volcanoes.

litic matrix; i.e., they are typical roots of extrusives. The liparite-dellenite dikes penetrate the shattered El'dzhurtin Tertiary granite (of Tyrna-Auz).

Table 6 gives absolute ages obtained by the K-Ar method for the Tyrna-Auz granitoid intrusion.

Liassic deposits in the western part of the Northern Caucasus are cut in places by rare dikes of diabasic rocks, in places by dikes of rocks approaching alkaline gabbroids in composition. Where these dikes are not associated with granitoid intrusions, they are not described here.

It should be noted at the same time that the Cretaceous extrusive granitoid bodies of the western part of the Northern Caucasus

Table 6

Absolute Age of the Tyrna-Auz Granitoids (in millions of years)

El'dzhurtin granite		Vein granosyenite porphyry		Dellenite
by biotite	by K-feldspar	overall	biotite	biotite
54	41	± 30	± 30	15
Determined by E.K. Gerling		Determined by the Dagestan affiliate of the Academy		Determined by the Inst. of Geoch. and Anal. Chem. of the Academy

Judging by their relationship with certain intrusive (extrusive) trachyliparites of the Northern Caucasus, the solitary granosyenite porphyry dikes may easily be taken for derivatives of a new intrusive-extrusive stage of a Cenozoic magmatic hearth, younger than the El'dzhurtin granite.

Externally, the granosyenite porphyry dikes are light-colored gray-green rocks with definite phenocrysts of feldspar. They are porphyrytic in texture with incrustations of plagioclase, andesite, oligoclase, and highly ferrous biotite in a finely crystalline matrix of anorthoclase, oligoclase, chlorite, accessory apatite and zircon.

Granite is shattered in the immediate vicinity of dikes; its biotite is chloritized. The vein rock is cryptogranular along the contacts, and penetrates the fractures in granite. The andesite-basalt veins have an internal structure characterized by a micro-

are not cut by dikes of comagmatic melanocratic rocks. However, they are penetrated by extrusive masses of a gabbroid type, as was found in cooperation with A.M. Borsuk in the 1958 field work along the upper course of Pshekha River.

Comagmatic melanocratic vein rocks are also lacking in intrusions of the so-called laccoliths of the Mineralovodsk region.

"LAMPROPHYRES," GRANODIORITES AND APLITES IN CERTAIN INTRUSIONS OF ARMENIA AND THE URALS

Our observations in the Gekharot granitoid massif are cited below as an example in Armenia.

The Gekharot intrusion is assumed to be correctly dated. It overlies Senonian deposits,

and its pebbles are present in the overlying Cenomanian. This intrusion is made up of granodiorite with a near-monzonite structure, and has a Pl composition: (andesine), biotite, common hornblende, and accessories (magnetite, zircon, apatite, titanite). These granodiorites are cut by hornblende-plagioclase rocks of a diorite type (highly alkaline), and aplites. A plagioclase-pyroxene dike with a SiO_2 content somewhat higher than usual for a gabbro occurs near the intrusive contact. The geologic relationship of this pyroxene gabbroid dike and the granodiorites is not clear because no direct contact is exposed.

Hornblende rocks of a diorite type cut the granodiorite, and the granodiorite is mylonitized at the contact. Thin injections of aplite penetrate the melanocratic vein rocks in places; as a rule, the vein rocks are a screen for the aplite injections. The chemical analyses of the Gekharot intrusive rocks are given in Table 4.

The considerable degree of alteration of the basic vein rocks, observed under the microscope as a development of prehnite, chlorite and less frequently of secondary potash feldspar, is also seen from the chemical analyses. The loss in heating, reaching nearly 4.5% in specimen 379/55, is due to a considerable extent to carbonatization of the vein rock. The ratio of radioactive elements U and Th also points to the superimposed effect of the acid derivatives on the basic vein rocks.

The absolute age determinations have yielded some interesting figures. A frequent check of the K-determination in different laboratories made it possible to establish the following ages as fairly reliable.

1. Granodiorites of the massif, 100 million years.

2. Pegmatoid formations of coarse K-Na-feldspar and quartz on K-feldspar, 90-95 million years.

3. Hornblende vein rocks cutting the granodiorites, 80-85 million years.

4. Aplite veinlets cutting the granodiorite, 75-80 million years.

5. A dike of pyroxene gabbroid in the contact with a granodiorite intrusion, 120 mil-

Table 7

Quantitative Mineral Composition of Certain Rocks of the Shartash Complex

Specimens	Q	Pl	K-Na-feldspar	Bi	Sphene	An and other accessories	Total
Mi-granite (Leucocratic)	29.6	37.4	31.8	1.5	--	--	100.3
Vein granosyenite porphyry (inclusions = 22.5%)	--	23.7	--	1.0	--	--	24.7
Ditto, matrix	24.0	18.0	18.0	12.9	2.6	0.3	75.8
An aplite veinlet, cutting the above	33.0	33.0	34.0	--	--	--	100.0

Chemical Composition of Melanocratic Vein Rock (granosyenite Cutting the Granite

Spec.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO
8/57	67.66	0.50	15.99	0.71	1.80	0.04	1.32

Spec.	CaO	Na_2O	K_2O	BaO	P_2O_5	Loss on Ignition	Sum
8/57	2.73	5.63	3.20	0.19	0.22	0.40	100.39

lion years.

These data, in conjunction with what has been noted above, suggest comagmatism of the first four groups; they also imply an older age for the gabbroids than for granodiorite intrusions.

Without pausing for the Akhpaț and Shnokh intrusions of Armenia, where the rock relationship is similar to that observed in the Gekharot complex, we shall consider the relationship of granitoids and vein rocks of the Shartash complex, near Sverdlovsk.

The obvious geologic relationships between the rocks of this complex are as follows: a) the granites are cut by gray, fine-grained rocks of a granosyenite porphyry type; b) both the granite and the vein granosyenite porphyries are cut by veins and veinlets of pegmatite and pegmatoid alaskite.

Table 7 gives the quantitative analysis of these rock varieties. A chemical analysis of the melanocratic vein rock has shown that it is granosyenite.

A characteristic feature of the granite is the metasomatic development of microcline intrusions. The granosyenite porphyries are truly crystalline rocks of a porphyritic structure.

Biotite in both the granites and vein granosyenite porphyries is greenish-yellow and poor in ferrous iron. Large xenoliths of a dark rock occur in the granite. Externally, they are in places similar to the dike rock, but they are in fact considerably metamorphosed formations of a mineral composition quite different from the vein granosyenite porphyries.

The data on the Shartash unequivocally show that the "lamprophyric" rocks (granosyenite porphyries) cut the granitoids of the complex and are in turn cut by the pegmatite and aplite veins.

The series, granodiorites -- granosyenite porphyries -- pegmatite-aplites, may be regarded, then, as having been formed in the course of a normal evolution of a granodiorite-granite magma. It is reasonable to associate the formation of the vein series with differentiation of the residual molten magma, approaching alkaline granite in composition.

SUMMARY

Summing up what has been said on our state of knowledge of vein series, including lamprophyres, it must be admitted that there is no unequivocal and satisfactory solution of this complex petrologic problem. This is explained to a considerable extent by inadequate knowledge of such factors as 1) the geologic relationship between intrusive rocks and assorted vein series; 2) composition and structure of intrusive rocks and dikes; 3) comparative data on dike rocks associated with intrusions and regionally developed dikes.

A brief resume of the main results of previous studies, along with the salient facts on dikes of the Northern Caucasus, Armenia and -- as a comparative example -- the Shartash complex (the Urals) lead to the following conclusions:

1. The term, "lamprophyres," does not indicate a definite petrographic type of extrusive rock and it should be used only as a composite name for melanocratic vein rocks associated with intrusive bodies of granitoids or alkaline rocks, comagmatic with these intrusives.

2. For a better differentiation of lamprophyric vein rocks from the others, occurring in veins, they should not include the regionally-developed dikes emplaced in both sedimentary and intrusive formations of different age; nor should they include vein rocks which cut the intrusive bodies while carrying structural and textural features identifying them as the roots of extrusive formations.

3. The evidence of comagmatism of the complex, the vein melanocratic and the vein leucocratic rocks is as follows: a) a proximity in age; the absolute age of the comagmatic rocks of this type should be within the limit of error of the determination method; b) a detailed analysis of those admixtures and accessory minerals which are common to all three.

4. The melanocratic vein rocks are caught in a "fork" between the intrusive rocks of the complex and the pegmatite-aplite veins, if the latter may be reasonably regarded as derivatives of the granodiorite-granite intrusion in which they are emplaced.

5. A special study is necessary of the relationship between the lamprophyre (in the above meaning of the term) vein rocks with complex (multiphase) granitoid intrusives of the alaskite stage which usually is the terminal type for this intrusive group.

6. The data on hand on comagmatism of lamprophyre and leucocratic vein rocks of an intrusive complex make it possible to state that the comagmatic lamprophyres and leucocratic veins are the differentiates of a molten residual after the crystallization of a

quartz-diorite-granidiorite-granite intrusion.

The composition of this residual magma is different for granitoid complexes differing in type and age. Consequently, a separation of the leucocratic differentiate, usually close to the quartz-feldspar eutectic, leads to isolation of an essentially mafic portion of the residual molten magma of a composition fluctuating from that of a gabbroid rock of a spessartite type to that of a syenite-type rock.

This assumption requires further verification by a detailed and comprehensive study of natural associations of intrusive rocks. The mechanism of this differentiation cannot be adequately explained, at the present time. However, the possibility of liquefaction of the residual molten magma, enriched in alkalies and water, into two phases of complementary composition should be considered.

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LIQUEFACTION PHENOMENA IN THE KALGANSKIY COMPLEX LAVAS

by

V. I. Lebedinskiy and Mo Ke-Min'

This paper describes drop-like spherulites from vitreous acid lavas of the Kalgan region, which have originated as a result of liquefaction of lava under near-surface conditions. A brief review is given of similar phenomena in lavas of other regions.

* * * * *

During his 1955 visit to Kalgan, the author noticed the peculiar vitreous acid lavas of the Kalgan complex, containing numerous brown, drop-like inclusions. It was supposed then that such sharp differentiation of a lava into volcanic glass and drop-like inclusions was a result of liquefaction. There are very few instances of liquefaction in rocks, and the very possibility of liquefaction in a silicate magma is disputed by many petrographers [1, 2, 3, 7]. Therefore, any data on this subject are of a great theoretical interest. V.I. Lebedinskiy, in cooperation with Mo Ke-min', who collected supplementary material on the Kalgan lavas, processed the material at hand. The present paper is a result of this work.

A resumé of the geology of the Kalgan extrusive complex is as follows. This complex is associated with that portion of the Precambrian crystalline Sino-Korean massif which is designated as "the Inner Mongolian axis" by Chinese geologists [10]. The Kalgan extrusives are developed in the northern part of Hopeh province (Fig. 1). They lie unconformably on the Nankow limestone of the Sinian Proterozoic and even more ancient Archean metamorphics of the Sangay system. These extrusives represent a complex volcanic sequence consisting of liparite, felsite, andesite, quartz trachyte, obsidian and perlite, tuff and tuffaceous breccia, all formed in eruptions of a central type.

There are two schools of thought on the date of the volcanic activity. According to G. Barbour [11], the Kalgan complex was formed during the first phase of the Yan'-shan' movements, i.e., at the close of the Jurassic; according to Chzhan Tsyan'-mo, it took place during the second phase of these movements, i.e., between the Late and Early Cretaceous. The overall thickness of the Kalgan extrusives is estimated at 640 to 790 meters.

The Kalgan extrusives are overlain by thick continental deposits of the Nan'tyan'myn' formation, Upper Cretaceous in age (sand, gravel, pebble beds), formed chiefly in the disintegration of these extrusives. After having been formed, the Kalgan extrusives were subjected to weak tectonic forces which produced flat folding and faulting. This, however, did not essentially alter the petrography of these rocks, so that at the present time most of the Kalgan extrusives persist in their original form.

The extrusive rocks are well exposed in the mountainous terrain of the Kalgan region: they form watersheds, from the foot of mountains to their summits. Because of the complex structure of this volcanic sequence, and of the presence of unevenly cemented pyroclastic beds, different in their resistance to erosion, the resulting relief forms are extremely varied and bizarre.

The vitreous lava bearing the drop-like spherulites occupies the upper part of the extrusive complex. This lava is a component of some of the fragments of the tuffaceous breccia located near the volcanic center (Fig. 2). This tuffaceous breccia is composed of coarse, angular fragments of black to green obsidian (commonly with perlite cleavage), liparite and vitreous lava with drop-like spherulites. The breccia cement is considerably disintegrated, saturated with moisture to the point of becoming a clayey greenish-yellow mass containing grains of volcanic glass. The original cement apparently was a pyroclastic material of volcanic sand and ash.

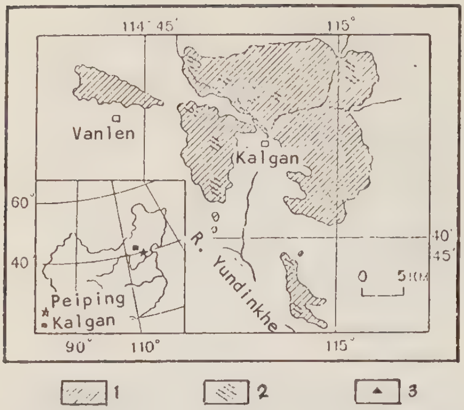

FIGURE 1. Index map of the Kalgan region

1 -- Kalgan volcanic complex; 2 -- outcrops of liparite and perlite; 3 -- location of perlite specimens carrying drop-like spherulites.

The lava specimens with drop-like spherulites have a very peculiar aspect. They are mostly a volcanic glass with a scattering of minute drop-like brown bodies. In some specimens, these bodies are comparatively rare, being isolated as slightly oblate spheroids; in others, they are much more numerous, accounting for 30 to 40 percent of the rock volume.

With a large number of such inclusions, they form complex growths of several brown spherulites or lentils rapidly wedging out, or fairly consistent intercalations, 2 to 6 mm thick, extending along the entire specimen. However, it is usually quite obvious that even these brown laminae consist of closely-knit spherulites.

The fine and rapidly wedging-out brown lentils are more uniform, with the individual drop-like spherulites not always discernible. These features of lavas carrying a large number of drop-like inclusions are seen on the sketch of a polarized specimen (Fig. 3).

The drop-like spherulites are clearly seen in specimens with a natural fracture surface (Fig. 4). They are rounded, slightly elongated, bean-shaped drab-brown bodies with a smooth, slightly glossy surface. Their diameter usually ranges from 2 to 8 mm. When united into aggregates, they form complex bodies reminiscent of kidney-shaped sinter formations. Figure 5 gives an idea of the spherulites.

The volcanic glass which predominates in the lavas is very uneven in color, but has a well-expressed flow structure manifested in an alternation of brown lentils and bands of coalescent drop-like spherulites. The volcanic glass is black, violet, drab, greenish-gray, with two or three sharply differing colors occurring in the same specimen.

Many specimens display a well-defined perlite cleavage. When such a specimen is struck or pressed with fingers, spherical pieces of glass, 1 to 6 mm, get loose, leaving small depressions on surface of the specimen (Fig. 4).

The vitreous matrix of lava is easily weathered, forming a friable, moist clayey mass, while the drop-like spherulites remain intact.

Under the microscope, the acid Kalgan lavas appear as vitreous liparite with perlite cleavage. The petrographic diversity of perlite lavas is considerable, depending on the presence or lack of a flow structure in the matrix, on the size of the spherulites, the degree of crystallization of the ground mass, etc.

The liparite consists of a vitreous matrix with sparse and small incrustations of sanidine and quartz. In fresher varieties of liparite, the matrix is a clear volcanic glass with a somewhat variable refractive index, depending on the color of the glass. Thus, for a large specimen shown in Figure 3, the refractive index was found to be 1.506 for the black band glass; 1.506 for gray-black segments; and 1.488 for light-gray bands.

Fresh volcanic glass contains great

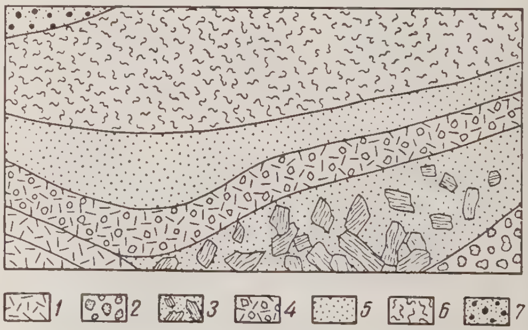

FIGURE 2. Diagrammatic cross-section of tuffaceous breccia with fragments of vitreous liparite carrying drop-like spherulites (near the village of Nan'tyan'myn').

1 -- massive crimson liparite; 2 -- lava breccia; 3 -- tuffaceous breccia containing vitreous liparites bearing the drop-like spherulites; 4 -- porous liparite; 5 -- poorly-cemented volcanic sand; 6 -- liparite tuff in which the liquefaction effect in fragments disappears, toward the top; 7 -- sand and conglomeratic rocks of the Nan'tyan'myn' formation.

FIGURE 3. Polished specimen of perlite liparite with drop-like spherulites. The spherulites are flattened ("squashed"), usually united into lenticular and banded bodies

amounts of both solitary and aggregate incipient crystallization forms - minute needles and spherulites. Most commonly, however, the volcanic glass is affected by poorly developed crystallization concentrated along the concentric partings of perlite cleavage where extremely fine films of a colorless felsitic material are formed. In more definitely crystalline segments of the matrix, small felsitic bodies originate within the perlite grains, alternating with transparent, brownish volcanic glass. Thus originates the peculiar hyaloplasmatic texture of the ground mass, with very rare minute idiomorphic crystals of zircon.

The liparite matrix also contains sporadic amygdules - elongated cavities oriented with the flow structure. On the periphery, they are fringed by a light-brown isotropic opal sinter layer, and their interior is filled with a radial aggregate of colorless chalcedony or granular quartz.

The small sanidine incrustations are thickly tabular, 0.2 to 1.5 mm long. There are traces of melting everywhere, expressed in wavy and smooth contours of the crystals. Crystalline cleavage is very well expressed along (010) and (001). The sanidine is colorless and perfectly homogeneous. Its constants are shown in Table 1 (following page).

The high-temperature quartz incrustations are smaller. Their diameter ranges from 0.1 to 0.5 mm, and they are isometric (this is explained by a strong development of the bipyramidal faces). All quartz incrustations exhibit traces of melting, although not as strong as the sanidine incrustations. The quartz is homogeneous, without inclusions, with an even extinction; it exhibits no characteristic fracturing.

The liparites represent leucocratic rocks generally containing no dark minerals. One thin section contained, however, a micro-incrustation of crypto-prismatic aegirine-augite with the following indexes: $2V = +60^\circ$, $c\gamma = 50^\circ$, $\gamma - \alpha = 0.029$; it is green and shows practically no pleochroism.

Various forms of drop-like spherulites are as pronounced in thin slides as they are

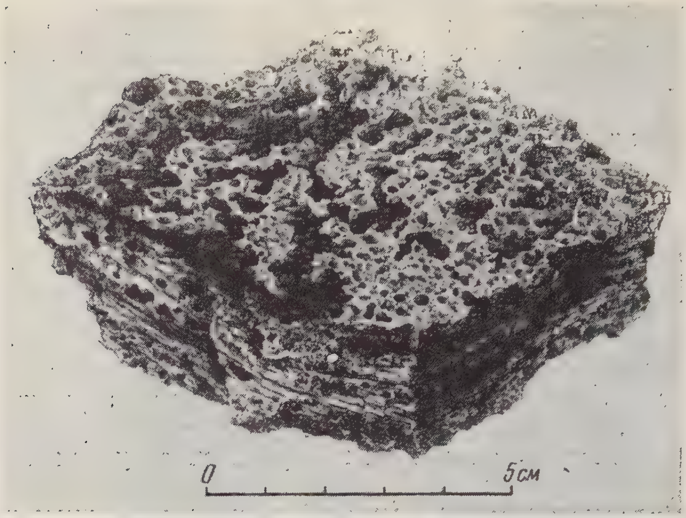

FIGURE 4. Specimen of perlite liparite with numerous drop-like structures. Flow structure is clearly noticeable on lateral surfaces

Table 1

γ	β	α	$\gamma - \alpha$	$-(001)\ \gamma$	$-(001)\ \beta$	$-(001)\ \alpha$	Dispersion	2V	Specific gravity
1.526	1.525	1.519	0.007	90°	5°	85°	$v > \rho$	-26-30°	2.587

in specimens. They are either regular spheres or else ellipsoidal and drop-like formations elongated parallel to the flow structure and scattered in the matrix, either individually or in growths. Regardless of their form, the drop-like spherulites are characterized by their perfectly smooth outline without any sharp bends. The well-expressed perlite cleavage of the matrix does not affect the drop-like spherulites.

The contact of the spherulites with the matrix is sharp, expressed in a gap, a few hundredths of a millimeter thick, between the two. Another mark of distinction between them is the radial structure of the spherulites which stops at their outer boundary, and the sizable difference in refractive indexes for the spherulites and volcanic glass. The spherulites are darker brown than the glass, and have a radial structure (Fig. 6).

The mineral composition of the drop-like spherulites has not been definitely established. Under the maximum magnification (500X) they are seen to consist of fine acicular crystals of a colorless mineral characterized by a refractive index less than 1.54, gray colors of first order interference, and positive elongation. The acicular crystals are straight to arched. The spherulite composition is alkaline-feldspathic.

The drop-like spherulites are not quite homogeneous. Scattered in them there are

FIGURE 5. Spherical and reniform drop-like spherulites. Sketched under a binocular microscope

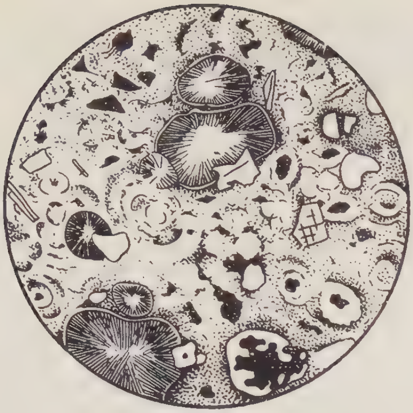

FIGURE 6. Drop-like radial inclusions in a perlite matrix.

Nicols parallel. 25X.

FIGURE 7. Streamlined, oriented flattened spherulites (dark, dotted border) with sanidine inclusions (white). Abundant perlite fractures in vitreous matrix.

Nicols parallel. 25X.

minute brown, semi-transparent bodies of iron oxides separated by light-brown glass and, what is most important, micro-inclusions of sanidine and quartz (Fig. 7). This, in conjunction with their drop-like form, their grouping into aggregates elongated parallel to the flow pattern, and the difference in their composition as compared with the matrix, all suggest that they originated in the process of crystallization of a lava, after separation of the sanidine and quartz micro-inclusions.

A chemical analysis was performed on carefully selected drop-like spherulites and the vitreous matrix, in order to determine their respective composition (Laboratory of the Peiping Geologic Exploration Institute; Huan Chzhun-yuan' and Van Syan'-tsey, analysts).

As shown in Table 2, there is a substantial difference in the chemical composition of drop-like spherulites and the matrix. The spherulites contain more SiO_2, NaO_2, and K_2O, and Less CaO, MgO and particularly H_2O.

A correlation on the basis of A.N. Zavaritskiy's description reveals that the vitreous matrix differs greatly from R. Daly's intermediate rock types, and is not correlative with any such type, while the drop-like spherulites are very close to rhyolites [6].

A standard mineral composition of volcanic glass may be inferred from P. Niggli's computation of its chemical composition.

SUMMARY

1. Perlite lavas consist of micro-inclusions, drop-like spherulites and a vitreous ground mass. Micro-inclusions represent the earliest separations while the spherulites and the matrix are the ultimate products of solidifying lava.

2. The later product of solidification — the spherulites — differs sharply from the vitreous matrix, in composition. The spherulites are liparitic, while the volcanic glass carries comparatively more water and less alkali. The streamline form of spherulites is extremely characteristic — rounded or ellipsoid — with evidence of flattening in the direction of flow. In groups of several individuals, the spherulites form lenticular bands oriented in the same direction.

3. The difference in composition and morphology of spherulites and the vitreous matrix may be satisfactorily explained by liquefaction of lava into two immiscible liquids. These liquids form an emulsion in which, depending on their ratios, spherules of one liquid are formed in the other. With an increase in volume of the subordinate liquid, its spherules form aggregates. In a flowing lava, these aggregates become bands and lentils of drop-like spherules. A rapid cooling of the lava maintained the distinction between the two liquids, as a predominant ground mass and subordinate drop-like bodies.

4. The crystallization of these bodies, leading to the formation of spherulites, took

Table 2

Oxides	% by weight		Computations after A. N. Zava-ritskiy	Volcanic glass	Drop-like spherulites
	Volcanic glass	Drop-like spherulites			
SiO_2	67,51	72,79	*a*	7,7	13,0
TiO_2	0,16	0,13	*c*	2,0	0,9
Al_2O_3	12,89	12,40	*b*	10,5	4,1
Fe_2O_3	2,38	2,04	*s*	79,8	82,0
FeO	0,50	0,24	*a'*	60	39
MnO	0,04	0,03	*f'*	26	46
MgO	0,90	0,36	*m'*	14	15
CaO	1,56	0,77	*n*	46	66
Na_2O	2,27	3,99	*Q*	+42,2	+37,1
K_2O	1,67	3,12			
P_2O_5	0,04	0,04			
CO_2	0,16	0,10			
H_2^-O	4,65	1,94			
H_2^+O	5,28	2,24			
Total	100,01	100,10			

Note: Comma represents decimal point

Table 3

Minerals	Volcanic glass	Drop-like spherulites	Minerals	Volcanic glass	Drop-like spherulites
Potash-feldspar	11,0	19,3	Corundum	3,4	0,8
Albite	23,1	36,8	Magnetite	1,5	0,5
Anorthite	7,3	3,0	Hematite	0,9	1,1
Quartz	44,5	35,2	Apatite	0,2	0,2
Cordierite	7,7	2,9	Calcite	0,4	0,2

place in the hardened lava.

The geologic literature cites a few examples of vitreous lavas with spherulites of a different composition, which may be regarded as the results of magma liquefaction. One of the more convincing is the quartz porphyry near Point Agaite, on the northern shore of Lake Superior, Canada, as described by T. Tanton [12]. The quartz porphyries occur in flows within a thick volcanic sequence. They carry drop-like spherulites different in composition than their vitreous matrix. The spherulites are distributed both singly and in lenticular aggregates elongated in the direction of flow. The vitreous substance of both the matrix and spherulites is partly crystallized. T. Tanton regards this phenomenon as a proof of liquefaction within a molten mass.

A very interesting case of liquefaction is the Yalguba variolites of Karelia, studied by F. Yu. Levinson-Lessing [9]. Here, too, the rock is differentiated into drop-like separations (variolites) and a vitreous ground mass. The variolites are very peculiar in composition, being nearest to quartz trap or andesite-dacite, while the ground mass corresponds to forellenstein. Difference in the oxide content between the variolites and the ground mass is about 12% for SiO_2; 4.5% for Al_2O_3; 6% for FeO; 5% for CaO; 3.5% for Na_2O; and 1% for K_2O. A characteristic chemical property of the ground mass is its higher water content (5.23% as against 1.27% in variolites). This is regarded by F. Yu. Levinson-Lessing as evidence of the importance of water in the liquefaction of magma. He points out that a similar differentiation of lava into two liquids is described by Fr. Slavik for a basic lava from Vodokhod, Czechoslovakia.

L.G. Kvasha [8] described spheroid andesite-dacites among the lavas of Arailer Mountain, Armenia. This spheroid rock, however, is similar to the Kalgan lavas only in its external aspect, since its vitreous spherulites are chemically indistinguishable from the essentially vitreous ground mass. L.G. Kvasha explains the origin of

the spherulites by "changes in the crystallized, originally homogeneous lava."

A paper by I.M. Volovikova [4] is the most detailed study known to us on the liquefaction in lavas. It is a result of a special study of upper Paleozoic felsite and quartz porphyry of the Chatkal' range, Central Asia, bearing in several localities a great number of spherulites of two types. One is represented by radial spheroidal crystals of an essentially K-feldspathic composition. The formation of these spheroidal crystals is connected with the incipient crystallization of a plastic-viscous magmatic substance under supercooling conditions. The other type is represented by very peculiar spherulites, very similar in their properties to those in the Kalgan vitreous liparites. The drop-like spherulites are spherical or ellipsoidal; they commonly "coalesce," forming lenticular intercalations.

The sketch of a quartz porphyry with bands of coalesced drop-like spherulites, in the Volovikow work, is quite similar to that of a vitreous liparite specimen with drop-like spherulites from the Kalgan complex. These spherulites originally were in a vitreous state (suggested by the preserved vitreous shell) and then underwent spherulitic crystallization with the formation of radial felsitic aggregates. The spherulites differ greatly in composition, SiO_2 content varying by about 7.5%; Al_2O_3 content varying by 3.0%; K_2O by 6.0% and H_2O by 1.0%. With chemical composition in terms of mineral composition, the drop-like spherulites are essentially orthoclase (50%), but the orthoclase content in the ground mass is insignificant (9.0%). An analysis of her own observations and of the published data leads I.M. Volovikova to the conclusion that the drop-like spherulites originated as a result of the liquefaction of a lava rich in alkalis into two immiscible liquids, just before the onset of crystallization.

A comparison of the properties of the Kalgan (C.P.R.) acid lavas bearing drop-like spherulites and those of the Chatkal' range (U.S.S.R.) shows their striking similarity, although there are some secondary differences, as well.

The authenticity of the liquefaction phenomena was demonstrated experimentally by D.P. Grigor'yev [5] who obtained under laboratory conditions a thin emulsion of two immiscible liquids, out of a fluorite-rich molten solution. One of the liquids was close to liparite, in composition. Liquefaction in Grigor'yev's experiments took place at about 1,250°C, close to the cooling temperature of lava. Thus, the possibility of liquefaction in natural magmas was confirmed experimentally.

The study of the Kalgan lavas with drop-like spherulites corroborates our conclusion on the authenticity of the liquefaction phenomena under extrusive conditions. A short review of the examples of liquefaction in lavas shows their large number. They no longer may be regarded as utterly strange, unusual phenomena.

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DISTRIBUTION OF TERTIARY RHODOPHYCEAE IN THE UKRAINIAN SOVIET SOCIALIST REPUBLIC AND THEIR RELATIONSHIP TO TRANSGRESSIONS OF THE SEA

by

V. P. Maslov and V. N. Utrobin

PRELIMINARY REMARKS

The study of red algae in the Mesozoic and Cenozoic of the U. S. S. R. is comparatively recent, although their presence in Ukrainian Tertiary beds was noted by many geologists (E. Eichwald, N. Barbot de Marnie, A. Alth, M. Lomnicki, A.D. Mikhal'skiy, V.D. Laskarev, and many others) as early as the nineteenth and early twentieth centuries. Soviet geologic and lithologic works have refined our knowledge on the position, distribution, environment and species of the Ukrainian red algae. In the Tertiary of the western Ukraine, they are found in the Helvetian sequence, widely distributed in the Tortonian of the southwestern edge of the Russian Platform (Podolia, Opol'ye and Rastoch'ye), and occur in isolated exposures throughout the Cis-Carpathian downwarp (Chaplya village). Calcareous red algae were found recently in the Paleogene of Crimea and eastern Carpathians.

RED ALGAE OF THE CRIMEAN PALEOGENE

Red algae occur in several units of the Crimean Tertiary: 1) in the Paleocene of Kuchuk-Karasu River; 2) in the Lower Eocene, near Nasypkoy village (Nasypnaya on new maps); 3) in the lower Eocene of Lysaya Mountain, near Feodosiya.[1] These two lower Eocene sections differ greatly from each other; we shall consider them in more detail, on the basis of our own data.

The Kuchuk-Karasu section (Fig. 1, no. 371), after V.G. Morozova, contains the following units:

1. Montian stage: limestone, white to yellowish, carrying small foraminifera; 7.8 meters thick.

2. Montian (?) or Thanetian (?): limestone, white to greenish, glauconitic, porous, with "Lithothamnium," and intercalations of greenish-gray marl on top, with "Lithothamnium" nodules; thickness, 3 to 4 meters.

3. Lutetian stage: medium-grained sandstone, calcareous, glauconitic, carrying nummulites, discocyclinas, terebratula, pecten, and numerous nodules and remains of red algae such as Lithothamnium microcellulosum Masl., L. tchernomoricum Masl., Lithophyllum mengaudi Lem.; 2.5 meters

4. White nummulitic limestone, 1.5 meters thick.

There is a gradual transition from glauconitic sandstone of unit 3 to the nummulitic sandstone of unit 4. The contacts of units 2 and 3 are complex: that between the glauconitic limestone (with its top consisting solely of nodules and bark of red algae) and overlying glauconitic sandstone (unit 3) is uneven, pebbly, cross-bedded, and full of nodules and bark fragments of red algae.

Glauconitic rocks are commonly associated with sea transgressions and regressions. In our case, there is an unquestionable break marked by the littoral pebbles and algae nodules between units 2 and 3.

A similar situation was observed in Lower Eocene rocks near the village of Nasypkoy (Fig. 1, no. 372), where the following section was recorded (from bottom to top):

1. Siltstone or sandstone, gray, tough, massive, interbedded every 0.2 meter with thin, fissile siltstones, 0.1 to 0.2 meter thick; total thickness over 30 meters.

2. Layer of a smoky blue marl with red algae nodules cemented together into larger nodules, and carrying pebbles of limestone,

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[1]The first two localities were found by V. G. Morozova (oral communication); the third one, by A. S. Moiseyev [15].

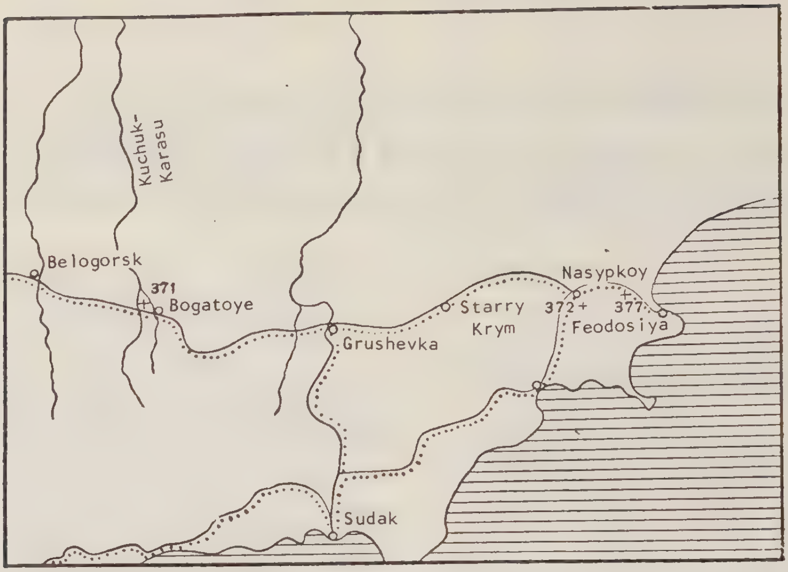

FIGURE 1. Red algae localities in Paleogene of the Crimea (cross-marks). Figures illustrate outcrops mentioned in text.

all cemented with sand or a gray sandy siltstone. Cross-bedding and evidence of reworking are present. The following red algae were identified: Lithophyllum carpaticum Lem., L. Mengaudi Lem., Mesophyllum schenki Howe, Lithothamnium microcellulosum Masl.; thickness, 0.2 meter (Fig. 2).

3. Gravel bed, massive, friable, calcareous, with pebbles of smoky blue marl and other fragments of red algae, with Lithophyllum carpaticum Lem., Archaeolithothamnium af. keenani Howe; one meter thick.

A transition to littoral facies was also observed (although without the glauconitic rocks), with red algae participating along with pebbles in the formation of the "complex layer" (unit 2) and the gravel bed (unit 3). Apparently, these are littoral deposits with algae nodules acting as pebbles rolled on the bottom, as is observed along the northern seashores.

A somewhat different section is exposed on Lysaya Mountain, near Feodosiya, where it is made up of dense smoky-blue, slaty lower Eocene marl carrying imprints of straight or arched bands and interbedded with detrital limestone; overall thickness, about 80 meters. The very top of the mountain is occupied by tougher, dark, thick-bedded and sandier marl with slight remains and nodules of red algae. These "algal" intercalations gradually thicken upward. However, they are extensively quarried for construction material and will probably be exhausted before long. Identified in nodules and detritus are Lithothamnium microcellulosum Masl., Lithophyllum mengaudi Lem. and Archaeolithothamnion cf. afonensis Masl.

Here, comparatively deep sea marl (200 to 250 m thick) appear to become more shallow, toward the top, with algae nodules appearing at a depth not exceeding 150

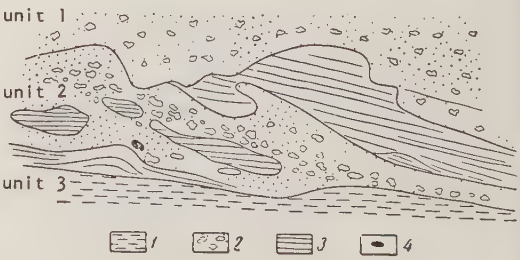

FIGURE 2. Cross-section exposed near Nasypkoy village.
1 -- sandstone and siltstone; 2 -- algae nodules in sandstone; 3 -- sandy silt; 4 -- pebbles. Figures to the left designate units described.

meters. There was no break in sedimentation; there are no overlying beds.[1]

RED ALGAE IN THE PALEOGENE OF THE EASTERN CARPATHIANS

First findings of red algae in Eastern Carpathians, along with corals, echinoid spicules and fragments of bryozoa, in conglomerate near Delyatin village on the Prut, are mentioned by C. Paul and E. Titze in their description of the Ropyanets beds [22]. Subsequently, red algae were observed by A. Alth in the Eastern Carpathians and along the Prut, Pistynka and Rybnitsa rivers, in rocks assigned to the tabular and hieroglyphic sequence [19]. W. Uhlig [28] found them in Paleogene deposits of the Polish Carpathians. A part of Alth's collection was processed by S. Grzybowski who noted that red algae and their fragments occur in conglomerate, dense limestone and calcareous quartz sandstone [20]. He identified Lithothamnium orulosum Grumb., L. suganum Rothpl., L. aschersoni Schwager., L. nummuliticum Gumb.

On the basis of his study of these species and other fossils, he believes the algae-bearing rocks to be Tertiary rather than Cretaceous.

Studies by V. N. Utrobin, in cooperation with L. V. Linetskaya, show that red algae occur only in the Pokutsk (tabular) beds[2] of the Upper Cretaceous and Paleogene Flysch of the Carpathian "skib" (scaly)[3] zone, and are lacking in other stratigraphic units.

Red algae in the Pokutsk (tabular) beds occur throughout the Pokutsk Carpathians (the uplifted Paleogene basement of the Cis-Carpathian downwarp) and in the Carpathian "skib" zone (exposures along the Prut, Nadvoryanskaya Bystritsa, Chechva, Sukelya, Oporda, Tysmenitsa, Podbuzhskaya Bystritsa, Dniester, and other rivers). Isolated nodules and small fragments of red algae occur there in dense calcareous gravel beds and coarse sandstones, less commonly in friable conglomerate and gravel beds with a sand-clay cement. The nodules are always small, not over 1.5 cm in diameter. As a rule, they are lacking in multicolored shale, siltstone and sandstone. The thickness of individual algae-bearing conglomerate and pebble beds is variable, changing from 10 cm to 1.5 meters. In those instances where a typical Flysch rhythm is present, the algae occur only in the lower, coarse-grained part of a rhythm. Occurring along with isolated nodules of red algae are numerous fragments of sponges and molluscs, echinoid spicules, occasional corals and foraminifera, including nummulites unfortunately not yet identified.

The stratigraphic position of the Pokutsk (tabular) beds remained obscure for a long time. A nummulite fauna was recently found in these beds, near Yaremche on the Prut, indicative of the lowermost Paleogene [17]. In addition, L. V. Linetskaya found in 1955, in conglomerate of the Yamrina and Vygoda formations in a number of localities in the "skib" zone (Strel'bichi, Storona, Sinevudsko, Vygoda, Lugi villages), isolated pebbles of sandstone and limestone carrying red algae and fragments of nummulites and whole discocyclines, i.e., Discocyclina scalaris Schlumb. (identified by L. V. Bashkirov) or else fully made up of them, which makes these pebbles Paleocene. The pebble material came from the northeast, from the site of the present Cis-Carpathian downwarp and could have been derived only from the Pokutsk beds.

The sharp change in the source of sediments at the boundary between the upper Stryy formation and Pokutsk beds, as reflected in the change in the pebble composition, along with the wider distribution of the Pokutsk beds as compared with the overlying Paleogene sediments, their lithologic properties and other data, suggests that these beds were formed under conditions of a marine transgression involving not only the Carpathians but a part of the Cis-Carpathian downwarp, as well.

RED ALGAE IN THE NEOGENE OF THE WESTERN UKRAINE

The lower Miocene "molasse" (Polyanitsk, Lower Vorotyshchensk, Zagorsk and Upper Vorotyshchensk formations), filling the interior zone of the Cis-Carpathian downwarp and missing in its outer zone, carry no red algae. The latter occur, as was noted above, only in deposits of the Helvetian and Tortonian stages.

The Helvetian and Tortonian stratigraphy

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[1]Besides these Crimean localities, a finding of Melobesia sp. plates in V. A. Krasheninnikov's thin sections should be mentioned. The specimen comes from a core taken out of a well north of Simferopol, from a depth of 200 meters, and represents a foraminiferal limestone with an assemblage of Upper Tortonian rhizopods.

[2]The name, "Pokutsk beds," was first introduced by K. Tolwinski [27].

[3]Skibs are a sequence of folded thrust blocks (T. N.).

and paleogeography of the western Ukraine are treated in a voluminous literature. They were a subject of study by many Austrian and Polish geologists (A. Alth, M. Lomnicki, W. Friedberg, J. Czarnocki, W. Teissejre, H. Teissejre). In the Soviet literature, the problems of stratigraphy and facies of these deposits are dealt with in papers by O.S. Vyalov [2], B.P. Zhizhchenko [5], V.P. Kozakova [6], M. Ya. Serova [18], L.N. Kudrin [8, 10], V.E. Livental' [11], A.A. Bogdanov and M. Ya. Serova [1], V.V. Glushko and L.S. Pishvanova [4], G.I. Molyavko [16] and others. Many investigators proposed schemes of differentiation for these deposits (O.S. Vyalov, B.G. Yurkova in cooperation with F.S. Putrey; B.P. Zhizhchenko; V.E. Livental' in cooperation with a number of geologists; V.P. Kozakova; V.N. Utrobin; L.N. Kudrin). These schemes modified and refined in many respects the earlier ideas of the Polish geologists; some of them (those of O.S. Vyalov, V.E. Livental', and V.N. Utrobin) have been accepted as a basis for detailed geologic surveying, the correlation of oil well sections, and for other purposes. The scope and nomenclature of individual stratigraphic Tortonian units is given below, after V.E. Livental' [11] and V.N. Utrobin (see Table 1). Its authenticity has been checked against extensive material data.

As recently established, the Paleogene and lower Miocene of the southwestern border of the Russian Platform (Rastoch'ye, Opol'ye, Podoliya) and the northern (outer) zone of the Cis-Carpathian downwarp[1] (northeastern Cis-Carpathia) witnessed the formation of sharply differentiated relief which essentially determined the spatial distribution of facies. The Helvetian and Tortonian deposits are characterized by considerable inconsistencies, both in space and in time. Their reconstruction is not always possible. Certain general considerations, however, may be set forth. In order to demonstrate the association of a wide development of red algae with individual transgressive stages and with facies, we may make use of certain basic data on the buried ancient pre-Helvetian surface and on the Helvetian and Tortonian paleogeography of the western Ukraine.

An ancient erosional surface along the northern edge of Opol'ye and Podoliya with relief features up to 70 meters, was first recognized by Polish and Austrian geologists [21, 23, 25, 29]. In recent years, this surface has been extended across the entire southwestern edge of the Russian Platform and the northern zone of the Cis-Carpathian downwarp. Going from the platform edge to the highest zone of the downwarp, and depending on the character and relief of the erosion surface, four regions or zones are separated, differing greatly from each other (Fig. 3).

Zone One, the farthest to the northeast, is featured by a nearly flat ancient surface and by narrow (50 to 200 m) erosional channels, 30 to 50 meters deep.

Zone two is characterized by more diversified relief with elevation differences up to 100 meters. A hilly surface is present in the northwest (Lvov region) in the area of development of friable Senonian marl. Individual ancient highlands there are not extensive (from 1 to 15 km^2), with flat (1 to 3°) slopes and broad (1 to 3 km) valleys separating them. The ancient surface of the southern part of this zone is a hilly plain dissected by upper parts of major river valleys (Stanislavsk, Khodorovsk, Pustomytovsk and Kolomyysk).

The ancient relief of Zones One and Two is represented in Silurian, Devonian and Upper Cretaceous rocks. The deepest depressions are filled with Helvetian and lower Tortonian deposits, with the overall thickness of the superposed deposits not large (25 to 100 m). Southwest of Zone Two there lies Zone Three, stretching in a narrow band along the platform edge, with a relief of some 350 meters. Zone Four embraces nearly all of the outer downwarp zone; its relief is over 600 meters.

The erosional aspect of these surfaces is nearly the same, with flat highlands and wide and deep ancient valleys, oriented generally northeast to southwest. Helvetian and lower Tortonian deposits (Baranovsk beds) only partly fill the deep depressions and are missing on tops and steep slopes of hills. Rocks of the upper lower Tortonian (gypsum-anhydrite formation) make up the enveloping structures.

The age of this ancient relief is determined as Paleogene and lower Miocene.

HELVETIAN STAGE

The Helvetian transgression had the character of an ingression along the edge of the platform (Fig. 4), with Oncophora beds (0.1 to 5 meters thick) deposited only on the lowest part of the ancient erosional surface. As a result of the submergence of highly dissected land along the northeastern border of the Oncophora basin, a system of shallow (up to 70 m deep) inlets and embayments originated.

[1]The terms, "southwestern boundary of the Russian Platform," "outer (northern) and inner (southern) zones of the Cis-Carpathian downwarp," are understood according to their modern meaning and position.

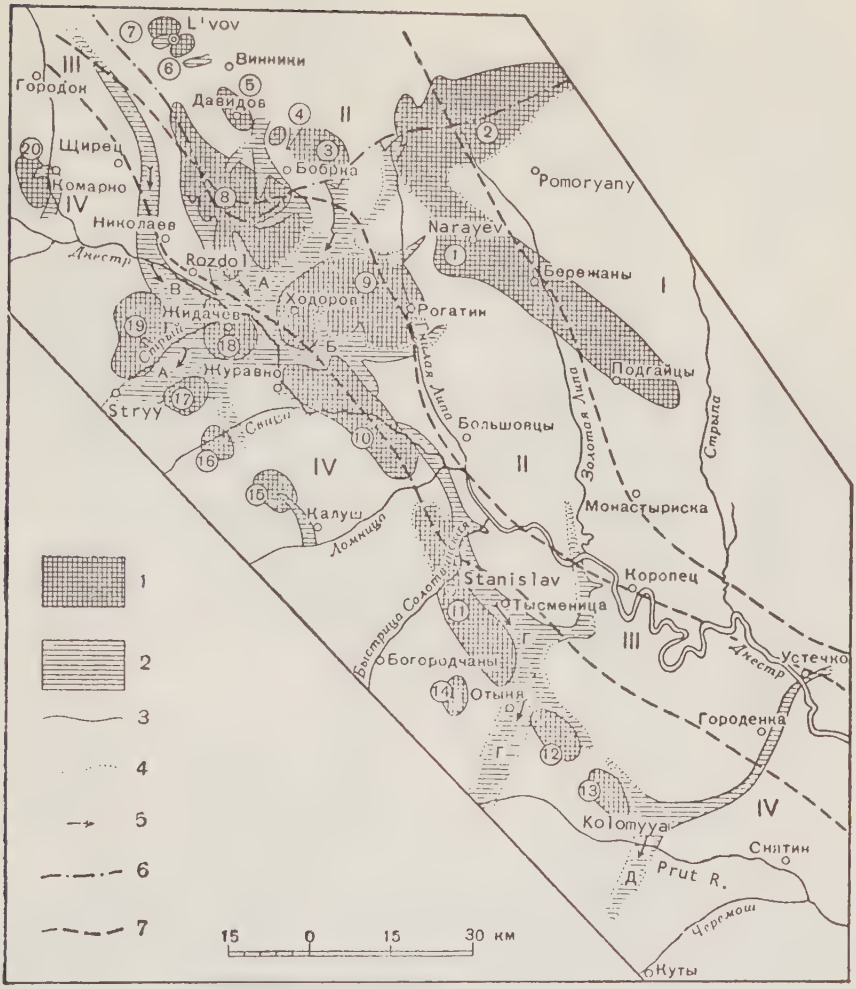

FIGURE 3. Diagram of principal ancient buried surfaces along the southwestern border of the Russian Platform and the outer zone of the Cis-Carpathian downwarp (compiled by V.N. Utrobin)

1 -- ancient erosional highlands; 2 -- ancient river valleys; 3 -- traced boundaries; 4 -- inferred boundaries; 5 -- direction of slope of ancient river valleys; 6 -- ancient water divide; 7 -- boundaries of provinces with different expressions of ancient relief.

Figures on map designate ancient highlands: 1 -- Narayev; 2 -- Gologoro-Zlochev; 3 -- Bobrka; 4 -- Khom; 5 -- Staroye Selo; 6 -- Chertovaya Skala; 7 -- Zashkov; 8 -- Vysokaya Mountain; 9 -- Khodorov; 10 -- Zhuravno; 11 -- Bratkov; 12 -- Lesnaya Slobodka; 13 -- Kolomyya; 14 -- Volosuv; 15 -- Zavadkov; 16 -- Balich; 17 -- Dashava; 18 -- Zhidachev; 19 -- Uger and Bil'che-Volitsa; 20 -- Komarno.

Ancient river valleys: A -- Khodorovsk; B -- Molodynichsk; C -- Pustomytovsk; D -- Stanislavsk; E -- Kolomyysk.

Relief in meters: I -- up to 50; II -- up to 100; III -- up to 350; IV -- over 350.

Correlative Stratigraphic Section of the Middle and Upper Miocene in the Southwestern Border Area of the Russian Platform and the Outer Zone of the Cis-Carpathian Downwarp.
(compiled by V.N. Utrobin)

<table>
<tr><th colspan="3">Age</th><th colspan="3">Outer zone of Cis-Carpathian downwarp</th><th>Southwestern edge of Russian Platform</th><th>Euxine-Caspian province</th></tr>
<tr><td rowspan="2">Upper Miocene</td><td rowspan="2">Sarmatian</td><td rowspan="2">Lower Sarmatian</td><td colspan="3">Volhynian group</td><td>Volhynian group</td><td>Volhynian group</td></tr>
<tr><td colspan="2">Konksk unit (beds with Cibicides badanensis)</td><td>Dashava formation</td><td>Konksk unit (beds with Cibicides badanensis)</td><td>Konksk unit (Veselyansk beds, after R.L. Merklin)</td></tr>
<tr><td rowspan="13">Middle Miocene</td><td rowspan="10">Tortonian</td><td rowspan="4">Upper Tortonian</td><td rowspan="4">Chernovtsy unit</td><td colspan="2">Break</td><td rowspan="2">Break</td><td rowspan="4">Chernovtsy unit (Kartvel' and Sartagan beds, after R.L. Merklin)</td></tr>
<tr><td>Kolomyysk beds</td><td rowspan="3">Kosov formation</td></tr>
<tr><td>Prut beds</td><td>Tarnopol' beds</td></tr>
<tr><td>Verbovetsk beds</td><td>Ratynsk (Kaiserwald) beds</td></tr>
<tr><td rowspan="6">Lower Tortonian</td><td colspan="3">Gypsum-anhydrite formation</td><td>Gypsum-anhydrite formation</td><td>Karagan unit</td></tr>
<tr><td colspan="3" rowspan="3">Break</td><td>Ervilia beds</td><td rowspan="3">Chokrak unit</td></tr>
<tr><td>Narayev beds</td></tr>
<tr><td>Opol'ye beds</td></tr>
<tr><td colspan="4">Index beds of ash tuffs and tuffites</td><td rowspan="2">Tarkhansk unit</td></tr>
<tr><td colspan="3">Baranovsk beds</td><td>Baranovsk beds</td></tr>
<tr><td rowspan="3">Helvetian</td><td rowspan="3"></td><td colspan="3">Freshwater beds</td><td>Freshwater beds</td><td rowspan="2">Kotsakhur unit</td></tr>
<tr><td colspan="3">Oncophora beds</td><td>Oncophora beds</td></tr>
<tr><td colspan="3">Break. A strongly eroded surface of Meso-Paleozoic deposits.</td><td>Break. A strongly eroded surface of Meso-Paleozoic deposits.</td><td></td></tr>
</table>

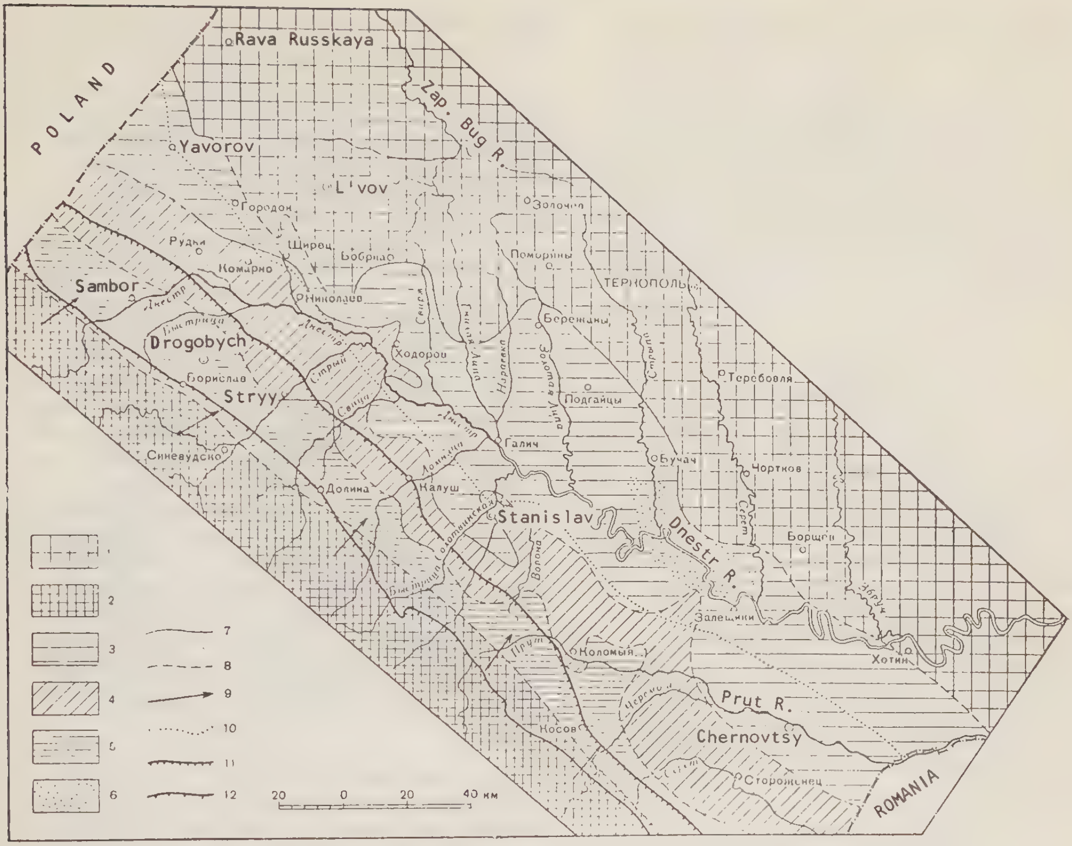

FIGURE 4. Paleogeographic map at the time of deposition of <u>Onchophora</u> beds and the Helvetian Balich formation.

1 -- flat land, with moderately diversified relief; 2 -- source of sediments, land with diversified relief; 3 -- belt of shallow and narrow embayments and harbors separated by stretches of land; 4 -- belt of relatively deep straits, gulfs and bays separated by land sections; 5 -- belt of piedmont alluvial plain; 6 -- area of the main distribution of red algae; 7 -- traced boundary lines; 8 -- inferred boundary lines; 9 -- direction of movement of clastic material; 10 -- boundary between the southwestern border of the Russian Platform and the outer zone of the Cis-Carpathian downwarp; 11 -- present line of thrust of inner zone over the outer; 12 -- present line of thrust of the Carpathian "skib" zone over the inner zone of the Cis-Carpathian downwarp.

Small rivers flowed into these isolated bodies of shallow water, where mixed-grain, strongly calcareous sands with <u>Oncophora socialis</u> Rzehak were laid down. In the shallow waters of the onshore part of open embayments and harbors, poorly sorted quartz sand was deposited along with considerable glauconite, and small pebbles and very rare nodules of red algae. Along with nodular sandy limestone, the Oncophora beds contain detrital limestone made up of small fragments of mollusc shells and red algae. Such lithology leads to a belief that banks of algae were located in the comparatively deep parts (25 to 30 m) of embayments, with fragments of algae and shells deposited in their peripheral deeper parts. Oyster beds of a small extent are described by L.N. Kudrin [8] among the <u>Oncophora</u> beds.

<u>Oncophora</u> beds are found in drilling on the slopes of ancient erosional highlands and valleys of the outer Cis-Carpathian downwarp (Ugersko, Bil'che-Volitsa, Rudki). The character of ancient relief and the lithology of these beds point to a system of comparatively wide and deep (150 to 200 m wide) straits, embayments and harbors separated by stretches of Upper Cretaceous deposits.

With an uplift at the close of the Helvetian, the sea receded from the southwestern edge of the platform and Cis-Carpathian downwarp. Fresh-water lakes were formed in some of the erosional depressions, where limestone and clay were deposited, with a fauna of

fresh-water and terrestrial molluscs (fresh-water beds).

The Helvetian ingression altered partly only the ancient erosional surface of the outer zone and the platform edge. Only its lowest areas were covered by a thin sequence of Oncophora and fresh-water beds, up to 60 meters thick. The main feature of the ancient land surface (considerable relief and alternation of highs and lows) remained nearly the same.

TORTONIAN STAGE

The lower Tortonian opens with the Baranovsk beds, transgressive over the older rocks. Their position in the section, along with the faunal differences and great changes in the paleogeography of the marine basins, observed at their contacts, allow separation of the Baranovsk beds as an independent stratigraphic unit. In complete Lower Tortonian sections, they are overlain by the Opol'ye beds, with a contact between the two well-marked by intercalations of ashy tuff or tuffite. These intercalations at the top of the Baranovsk beds occur in many localities and constitute a fine marker in correlating the Tortonian sections of the platform and the downwarp.

Because of the dissected surface and small submergence of the Rastoch'ye, Opol'ye and Podoliya areas, as compared with the Cis-Carpathia, the Baranovsk transgression, like the Helvetian, was of an ingressive type. A belt of shallow embayments, straits, lagoons and harbors was formed along the northeastern border of the Baranovsk basin. This, in turn, brought about a considerable variety in facies (Fig. 5). The greatest development of facies with red algae took place along the northeastern border of the basin, in its shallowest part (L'vov, Bobrka, Peremyshlyany, Berezhany).

Some investigators [3] erroneously identify the algal nodular limestone of the Baranovsk beds as the first or lower "Lithothamnium" unit. A study of sections shows, however, that algal limestones of these beds do not form an independent, even locally, stratigraphic unit, occurring instead in different parts of the section, depending on the facies.

As in the Helvetian, the Baranovsk red algae are observed in the following environments: 1) as nodules or lumps in littoral ill-sorted quartz sand; 2) shallow algal banks and shoals, where coarse nodules and lumps were deposited; 3) comparatively deeper (50 to 100 m) detrital limestone and marl made up of fragments and small nodules of red algae and containing numerous small oysters and other pelecypods and gastropods.

In the outer downwarp zone and in certain marginal areas of the platform, the Baranovsk sea was an open basin with isolated islands marking the summits of ancient erosional highs. The depth of this basin was variable, attaining 600 to 700 meters. Over most of the area, the Baranovsk beds are represented by sandy marl and calcareous clay with a rich fauna of thin-shelled pelecypods: Amussium denutatum Reuss., A. cristatum Br. var. badensis Font., A. comitatum Font., Fhracia ventricoas Phil., and planktonic, rarely benthonic, foraminifera. This facies was deposited in comparatively shallow areas (over 100 m) of submerged large valleys and on middle and lower slopes of erosional highs. The shallow (up to 100 m) areas of their summits and upper slopes were the depositional sites of quartz-glauconitic, argillaceous sands carrying a rich fauna of a normally saline marine basin. Occasional nodules of red algae occur in these sands. In the surf zone of comparative large stretches of island shores, conglomerate and ill-sorted sandstone with pebbles of Cretaceous rocks were deposited (Ostranya, Tysmenitsa, Bratkovitsy villages).

Baranovsk beds of the outer downwarp zone are made of globigerina marl and less common calcareous siltstone and shale, with planktonic foraminifera being the main rock component. The depth of deposition of this facies is unknown. A narrow band of shallow sea was located southwest of this deep basin, where quartz-glauconitic sands were laid down, with a rich fauna of pelecypods and benthonic foraminifera. The maximum submersion occurred in the interior Cis-Carpathian downwarp zone.

At the very end of Baranovsk time, after the deposition of ash tuff, the boundary of the Lower Tortonian marine basin underwent a radical change. A narrow marine strait or inlet was formed in the area of Rasoch'ye, Opol'ye and Podoliya, here called the Podol'sk strait. The Opol'sk, Narayev and Ervilia beds were deposited there, while a sizeable portion of the Cis-Carpathia, along with the southern edge of Opol'ye and Podoliya, stood dry. A marine basin persisted only in extreme northwestern Cis-Carpathia, in the Sambor area and farther on, in Poland (Sambor bay).

Much terrigenous sandy material entered the northwestern part of the Podol'sk strait, in Opol'sk time. Accordingly, sandy sediments predominate there, with subordinate carbonates. The sandy material reached the central and southeastern parts of the strait to a limited extent only, allowing a wide

FIGURE 5. Paleogeographic map at the time of deposition of the Lower Tortonian Baranovsk beds.

1 -- plain of low relief; 2 -- belt of shallow embayments, straits, lagoons and harbors separated by long stretches of land; 3 -- open marine basin, up to 700 m deep, with few islands; 4 -- open basin, no less than 1,000 m deep; 5 -- shallow zone along the southwestern shore of the basin; 6 -- area of the greatest development of red algae; 7 -- traced boundaries; 8 -- inferred boundaries; 9 -- present boundary between the outer zone of the Cis-Carpathian downwarp and the southwestern border of the Russian Platform; 10 -- line of thrust of the inner zone over the outer; 11 -- line of thrust of the Carpathian "skib" zone over the inner Carpathian downwarp zone.

development of red algae. (Fig. 6). Banks and shoals originated in the elevated bottom areas. They persisted for a long time and were the sites of accumulation of large nodules of red algae (Berezhany, Narayev, Kuropatniki, Monastyriska and other areas). Deeper areas about these banks and shoals were fringed with wide bands of calcareous detritus washed off the higher elevations. The frequent alternations of detrital and algal limestones suggest that red algae took over the depressed area whenever the supply of detritus was slackening. Over the deepest bottom areas — the sites of ancient erosional depressions with only the finest calcareous and argillaceous material — lime-clay oozes were deposited, with dwarfed, branching, red algae nodules and numerous bryozoa (Podgaytsy, Beremyany, Berezhany, and other villages).

Sandy material of Opol'sk age was distributed extremely unevenly. As first recognized by H. Teissejre [25], the sand accumulation depended essentially on bottom relief and the direction of currents. For instance, thick sands were deposited in some of the most depressed areas (Romanovka). The Opol'sk sand and sandstone are sharply curtailed or altogether missing along the northwestern slopes of erosional highs, but they thicken abruptly, up to 100 meters, on the southeastern slopes (Khom, Staroye Selo, Bobrka, and other areas). Despite a certain consistency

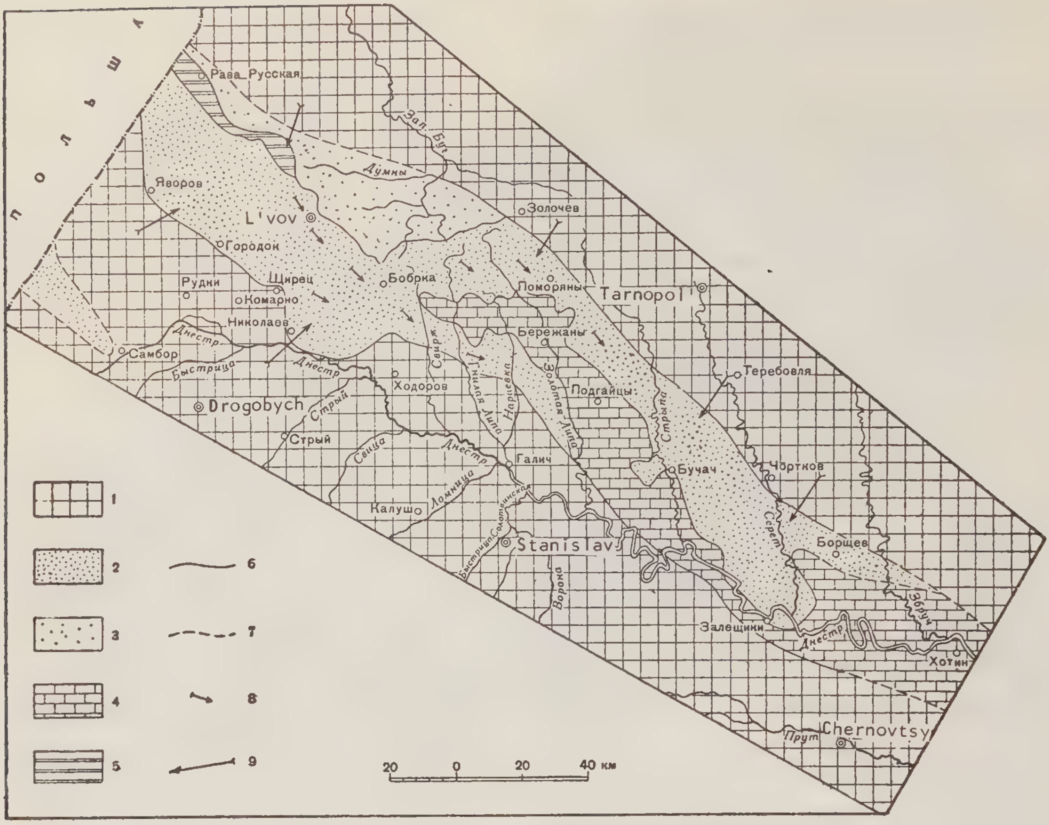

FIGURE 6. Paleogeographic map at the time of deposition of the Opel'sk beds.

1 -- source area with low relief; 2 -- area of best development of shallow-water sandy sediments; 3 -- eroded sandy deposits; 4 -- area of best development of calcareous depsoits; 5 -- area of littoral brackish-water harbors and embayments with areno-argillaceous coal-bearing deposits; 6 -- traced boundaries; 7 -- inferred boundaries; 8 -- direction of movement of sandy material, as determined by the prevailing dips of cross-bedding and the trend of sandy ridges; 9 -- direction of movement of clastic material.

in depositional conditions, an erratic flow of clastic material, along with the shallow depth and the diversity of bottom relief, resulted in great lateral variation in the Opol'sk facies.

Judging by its sediments, the Podol'sk strait was not deep in Opol'sk time, with the maximum depths not exceeding 150 meters. Toward the close of that period, the most depressed bottom areas were covered with sediments.

The spatial distribution of red algae throughout the Opol'sk beds, deposited in a marine basin of normal salinity, shows that they grow and multiply best under shallow conditions, in the absence of terrigenous material (as noted by I. K. Korolyuk).

Throughout a considerable part of the basin, on sites of early Opol'sk banks and on the most elevated places, extensive shallows were formed with rapidly accumulating red algae nodules. Detrital limestone, made up of algal fragments, was laid down along the depressed periphery of these shallows. Whenever the amount of incoming clastic material decreased, red algae spread over these deeper parts. For instance, at the Demiya quarry, massive detrital limestone, 8 meters thick, with beds dipping west at 10°, is overlain by horizontal, thick-bedded algal nodular limestone, with an apparent thickness of 5 meters. Such alternation of algal nodular and detrital limestone is commonly observed in outcrops at Malinovtsy, Firleyev, Dobrovody, Glebovichi, Narayev, Podgaytsy villages and in many other places. The dip of detrital limestone beds should be regarded as initial, as pointed out by L. N. Kudrin [9].

A slight broadening of Podol'sk bay took

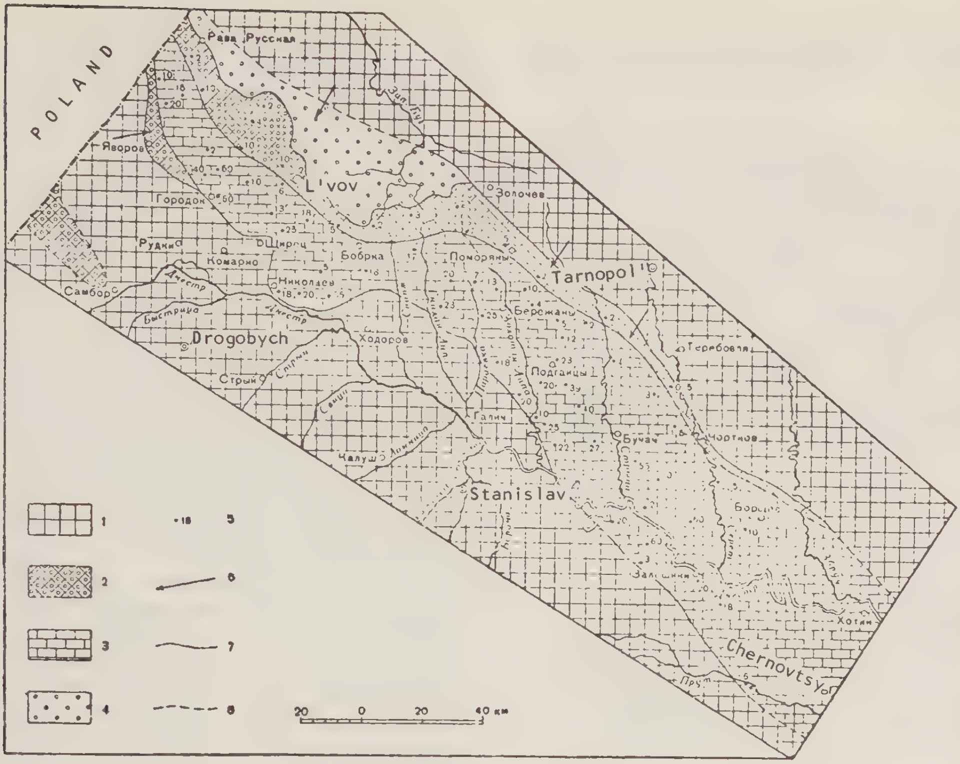

FIGURE 7. Paleogeographic map at the time of deposition of the Narayev beds.

1 -- source area of low relief; 2 -- shallow sandy calcareous deposits; 3 -- shallow calcareous deposits: algal nodular banks, long enduring and detrital limestone of bank peripheries; 4 -- eroded sand-lime deposits; 5 -- thickness of Narayev beds (in meters); 6 -- direction of movement of clastic material; 7 -- traced boundaries; 8 -- inferred boundaries.

place at the onset of Narayev deposition. The Narayev beds are sometimes called the second Lithothamnium unit [3]. The inflow of clastic material from the surrounding land decreased abruptly, leading to an even more favorable development of red algae. They spread over the entire area of the basin. Sandy material kept coming in only in the extreme northwest (Rastoch'ye) and along the northeastern shore (Fig. 7). Shallow and littoral-marine, sandy-lime sediments kept accumulating there, represented by sandy limestone and calcareous sandstone with large nodules of red algae. In only a few localities (Ivan Franko, Nesterov, Rava Russkaya) with an abundance of sandy material, were sands with dwarfed nodules of red algae deposited. Thus, the steep dips of the Narayev beds near Khrustovo, Pustomyty, Nikolayev and Obroshi villages are explained by their descent into the deep Pustomytovsk erosional valley.

One cannot agree with L. N. Kudrin's concept of two reef-oncoid zones, formed in Narayev time (middle unit of the Lower Tortonian, after L. N. Kudrin) and associated with shallow anticlinal structures with a wavy axis.

As demonstrated by V. N. Utrobin's study there are no anticlinal folds with undulating axes, either in the Cretaceous or the Tertiary along the line, Gorodok-Razdol and Borshchev-Berezhany. A gentle anticlinal uplift, discovered by seismic methods in the Mesozoic west of L'vov, has a different trend and is not reflected in the Tertiary beds. The stratified structure of the Narayev beds, made up of algal nodular and detrital limestone, along with the lack of typically massive reef rocks such as in the Upper Tortonian reefs of Medobor, points to the lack of any reef zones. The general southerly thickening of these beds suggests more favorable conditions for the growth of red algae along the southwestern boundary of the basin where there was practically no clastic material. Certain local thickening of the Narayev beds, observed in a number of localities (Berezhany, Podvysokoye, Narayev, and others), is connected

with the rapid growth of red algae and the accumulation of their nodules and fine detritus under the peripheral conditions of flat shoals and banks.

V. P. Maslov identified the following species of red algae, from the collection of D. P. Naydin: Lithothamnium saxorum Cepeder, L. undulatum Ceped., L. andrusovi Lem., L. Magnum Ceped., L. taurinense var. reticulatum Masl., L. praefruticulosum Masl., L. microcellulosum var. junior Masl., Archaeolithothamnium keenani var. Ivovicum Masl., Lithophyllum rotundum Ceped., L. albanense Lem., L. (Dermatholithon) nataliae Masl., Melobesia (Lithoporella) parasitica Masl., M. (L.) parasitica var. grandis Masl., Mesophyllum schenki var. corticesum Masl.

In Narayev time, shallow-water sandy limestone, made up of large red algae nodules was deposited in Sambor bay.

After that, a very narrow, somewhat brackish embayment or lagoon was formed in the central and northwestern parts of the Podol'sk strait, with the deposition of thin (0.1 to 1.5 m thick) limestones or sandstones full of Ervilia pusilla Phil. and Modiola hoernesi Reuss. shells (Ervilia beds).

Toward the close of the Lower Tortonian, the Cis-Carpathian province along with some areas of Opol'ye and Podoliya underwent a considerable downwarping.

A lagoonal basin was formed there, whose chemical deposits (gypsum and anydrite) were laid down unconformably over varous stratigraphic units.

The onset of the Upper Tortonian sedimentary cycle was marked by a major marine transgression and submergence not only of the downwarp but the entire southwestern border of the Russian Platform, as well. This submergence and the influx of marine water into the basin of deposition of gypsum and anhydrite brought about a radical change in sedimentary conditions and a corresponding diversity of facies in the lowermost Upper Tortonian. The beds representing this interval are usually identified as the Ratynsk (Kaiserwald) beds, at the edge of the platform; and the Verbovetsk beds, in the downwarp. The former, judging from ashy tuff intercalations, correspond only to the lower part of the latter. In the "teltr" [a Russian term for isolated rocky ridges characteristic for this area] zone and the surrounding areas, I. K. Korolyuk [7] separated these beds as unit B. In some sections, however (Privorot'ye, Gusyatin, Kamenets-Podol'sk, Chernokozintsy, Knyazhpol' and others), she erroneously assigned to this unit algal "Lithothamnium" limestone which we believe belongs to the overlying Tarnopol' beds. Red algae, as a rule, are lacking in the Ratynsk beds, with occasional nodules observed only in sandy deposits along the northeastern boundary. As early as this initial stage of the Upper Tortonian transgression, the part of southern Podoliya between Strypa and Zbruch rivers witnessed the formation of a downwarp more profound than in the surrounding areas of the southeastern border of the Russian Platform. In this zone or belt, as in the downwarp, the Ratynsk beds are represented by deeper-water sediments.

The Ratynsk (Kaiserwald) beds are overlain on the platform edge by Tarnopol' (upper Lithothhalmium) beds. As noted by H. Tessejre [25] and I. K. Korolyuk [7], this section is locally subdivided into two parts having a somewhat different lithologic composition. There is no agreement as to their correlation with contemporaneous formations of the Cis-Carpathian downwarp [1, 6, 10, 17]. In a number of sections, the uppermost Tarnopol' beds carry a layer of ash, tuff and tuffite, 0.2 to 1 m thick. Tracing this layer, as well as the character of the fauna of these beds, from section to section, suggests that the Tarnopol' beds are correlative only with the base of the Upper Tortonian section in the Cis-Carpathian downwarp (upper part of the Verbovetsk and lower part of Prut beds). The wide development of red algae, along with the rich fauna of these beds, points to their deposition in a comparatively shallow marine basin of normal salinity.

The time of deposition of the Tarnopol' beds coincides with the maximum areal development of the Upper Tortonian transgression and corresponds to its second stage. As compared with the first stage (Ratynsk), this is a deeper submergence of the basin with a change in dimensions and configuration. The small insular uplift of Ratynsk time probably grew larger, dividing the basin into two wide straits which made a single body in the middle course of the Dniester, in the Gorodenka, Zaleshchiki and Khotin areas.

In the first half of Tarnopol' time, essentially quartz sand with a rich fauna and coarse nodules of red algae, as well as other rocks, were deposited in the northeast, along the littoral part of the basin (Fig. 8, 9). Farther away from shore, there lay a comparatively wide belt of banks or shoals with large algal nodules and less common algal limestone. Waves and currents carried the bulk of detritus off these banks and to deeper parts of the basin where they formed a comparatively narrow band of "plank" detrital limestone, resting as a rule at the base of reef limestones. In the deeper, southwestern part of the basin, where a considerable

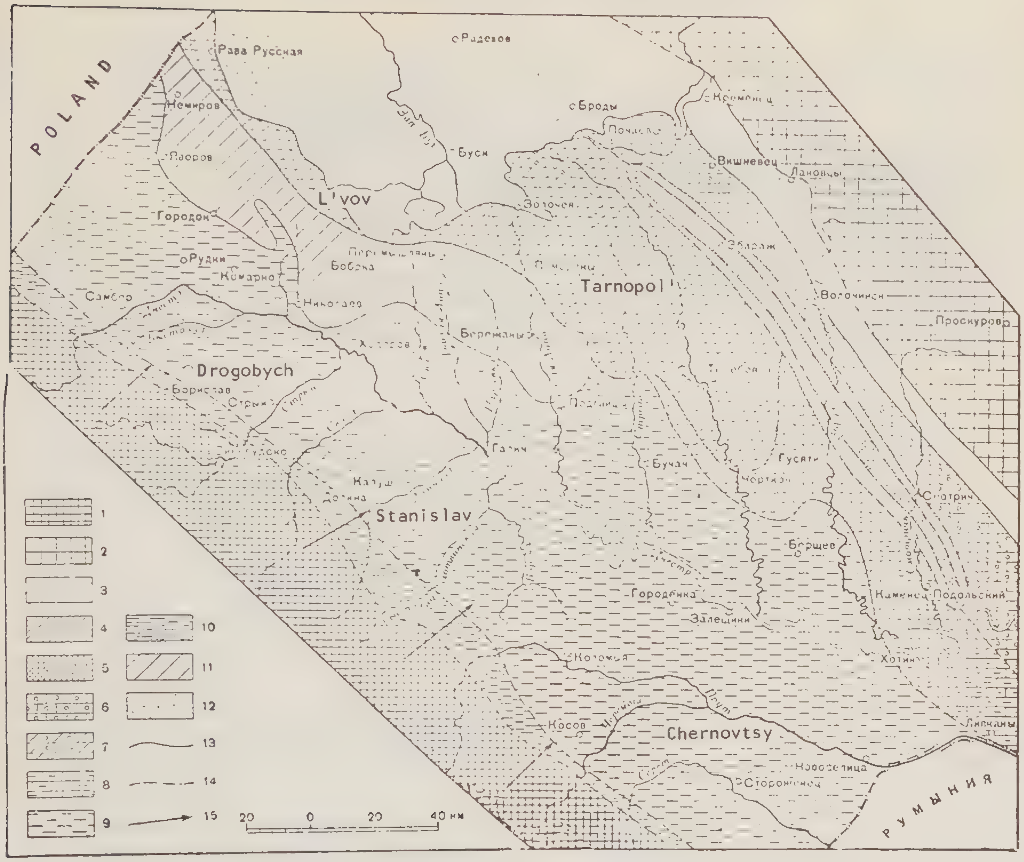

FIGURE 8. Paleogeographic map of the maximum upper Tortonian transgression (Tarnopol' beds, upper part of Verbovetsk and lower part of Prut beds).

1 -- source area, considerably elevated above the Tortonian sea level; 2 -- source area with low relief; 3 -- shallow littoral sandy calcareous deposits; 4 -- fringe zone of algal banks and reef massifs; 5 -- zone of algal bioherms in the second half of Tarnopol' time; 6 -- area of algal nodular facies deposited under shallow conditions; 7 -- area of comparatively deep (50 to 100 m) algal banks; 8 -- calcareous clay deposits with occasional dwarfed red algae; 9 -- comparatively deep-water calcareous clay deposits with thin-walled pectens and an assemblage of planktonic, less commonly benthonic, foraminifera; 10 -- inferred area of shallow areno-argillaceous deposits along the southeastern shore of upper Tortonian sea; 11 -- area of no Tarnopol' beds (probably a low, flat land); 12 -- area of eroded upper Tortonian deposits; 13 -- traced boundaries; 14 -- inferred boundaries; 15 -- direction of movement of clastic material.

amount of terrigenous clay-carbonate material accumulated, there originated deeper (at 100 to 150 m) algal banks with small dendritic nodules of red algae. Algal limestone with a sizable amount of marl was deposited there. Oysters took over the elevated bottom areas, forming extensive oyster banks, especially at the onset of Tarnopol' time. South of the area of Chortkov, Grimaylov, Gusyatin, and Kamenets-Podol'sk, the lower part of these beds is represented by highly calcareous clay and marl with occasional small red algae. Still farther southwest, the Tarnopol' beds are made up of calcareous clay deposited in comparatively deep waters (over 200 m).

Further deepening and broadening of the Tarnopol' strait took place in the second half of Tarnopol' time. Shallow-water sandy-lime rocks were deposited in its northeastern part. Farther west, there lay a belt of shallow algal banks. Algal nodular limestone with much marl were deposited over it. A zone of algal reefs of assorted limestones originated along the abrupt depth changes, usually above the earlier Tarnopol' "plank" limestone. This Upper Tortonian reef zone is described in detail by I. K. Korolyuk [7]; we only note that its coincidence with the locus of an

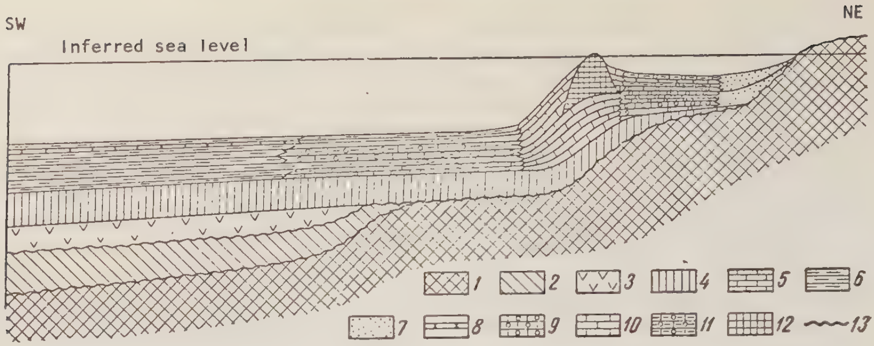

FIGURE 9. Paleogeographic cross-section along line Satanov-Gorodenka, at the time of deposition of Upper Tortonian Ratynsk and Tarnopol' beds.

1 -- Paleozoic and Mesozoic deposits; 2 -- Lower Tortonian deposits; 3 -- gypsum-anyhdrite formation; 4 -- Ratyn beds; 5 -- chemical calcareous oozes; 6 -- calcareous clay oozes; 7 -- shallow and littoral sand with occasional nodules of red algae and less frequent shell-limestone beds or sands with a rich fauna; 8 -- ash tuff and tuffite; 9 -- shallow-water algal banks; 10 -- fringes of algal banks and reef massifs; 11 -- comparatively deep (up to 150 m) algal banks; 12 -- bioherm reef massif; 13 -- eroded surface.

abrupt change in depth of the Upper Tortonian basin is probably due to its position above a junction of two gentle anticlines.

Detrital limestone, formed in the disintegration of reefs, are locally present along the periphery of reef massifs. Southwest of the reef massifs' fringe zone, the upper part of the Tarnopol' beds is made up mostly of argillaceous limestone with small nodules and branches of red algae. In a number of localities, this limestone changes to gray calcareous clay and marl with an abundance of thin-walled pectenoid shells, Chlamys galiciana Favre., Chl. neymayri Hilb., and rare nodules of red algae. In the areas of Buchach, Tluste, Borshchev, the upper Tarnopol' clay-marl-limestone facies rests upon calcareous clay. Such lithology of the Tarnopol' beds, along with the thin-walled pecten fauna, suggests that the southwestern part of Tarnopol' strait, southwest of the reef zone, was considerably deeper than the eastern part, probably no less than 100 to 150 meters deep.

V.P. Maslov [14] identified the following Tarnopol' species of red algae from the collection of I.K. Korolyuk: Lithothamnium saxorum Ceped., L. saxorum var. korolukae Masl., L. undulatum Cap., L. andrusovi Lem., L. taurinense var. reticulatum Masl., L. bullaense Masl., L. toltraense Masl., L. microcellulosum var. junior Masl., L. microphyllum Masl., Archaeolithothamnium irinae Masl., Lithophyllum capederi Lem., L. prelichenoides Lem., L. ramosissimum (Reus.), L. albanensis Lem. L. (Dermatolithon) uccrainicum Masl., L. (D) nataliae Masl., Melobesia (Lithoporella) parasitica Masl., Jania toltriea Masl.

The third stage of development of the Upper Tortonian basin, corresponding to the deposition of the upper and greater part of Prut beds, is marked by its restriction and shallowing. The sea receded from almost the entire southwestern edge of the Russian Platform, persisting only in the Cis-Carpathian downwarp. Red algae disappeared altogether. At the close of the Late Tortonian (Kolomyya beds), the Cis-Carpathian marine basin contracted still more, before disappearing completely.

Thus, the Upper Tortonian witnessed a coincidence of wide development of red algae with the beginning of a major transgressive sedimentary cycle, and their total absence at the end of it. At the maximum transgression, red algae became a predominant rock-forming factor, as they spread throughout a vast region.

In the spring of 1957, with the kind cooperation of the Ukrneftrazvedka (Ukrainian Petroleum Exploration), we visited a number of outcrops. As a result, a correlation cross-section was compiled for the Zolochev area, east of L'vov, in the Gologory and Bogutin highlands, near Pomoryany village. This cross-section (Fig. 10) shows three exposures embracing the Upper and Lower Tortonian and resting upon Cretaceous marl. Exposed at Slavita and Torgov villages are: 1) Campanian Cretaceous marl; 2) a full Lower

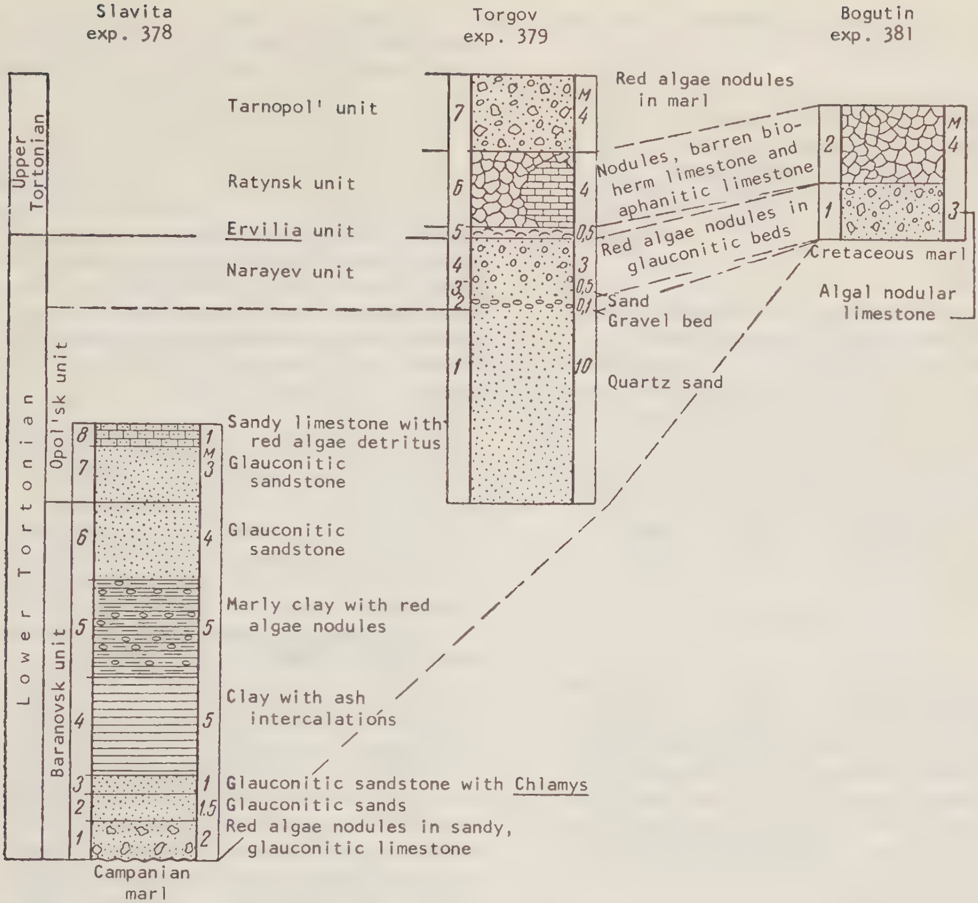

FIGURE 10. Stratigraphic cross-section of Tortonian sequence in the Zlochev-Pomoryany Area (compiled by V.P. Maslov)

Figures to the left of columns -- bed numbers; to the right -- thickness in meters.

Tortonian sequence; subdivided by V.N. Utrobin into the Baranovsk, Opol'sk, Narayev and Ervilia lithologic units ("beds" of V.N. Utrobin); and 3) a full Upper Tortonian sequence, subdivided into the Ratynsk and Tarnopol' lithologic units. Exposed in the Bogutin outcrop are 1) Cretaceous marl, lying at an elevation over 40 m above the Lower Tortonian; 2) Narayev unit; and 3) Ratynsk unit. Not counting the unexposed or recently eroded Upper Tarnopol' unit, the Baranovsk, Opol'sk and Ervilia units are missing in this section. In addition a pebble bed, 0.1 meter thick, and sand (0.3 m thick), covered by a layer of abundant red algae nodules, are present at the base of the Narayev unit, in the Torgov exposure. In the Bogutin exposure, this layer rests directly on the Cretaceous. The pebble-sand of the Torgov exposure apparently represented subaerial conditions at Bogutin. All deposits are flat-lying without any traces of tectonic displacements.

This cross-section, in conjunction with the work of petroleum and geologic organizations, leads to the following broad premises:

1. Tertiary deposits rest upon a pronounced erosional surface of Cretaceous age cutting across a dissected surface of Paleozoic age.

2. Different Tertiary stratigraphic units have different lateral distribution. Specifically, Helvetian deposits, formed as a result of a typical ingression, occupy only the deepest depressions in this ancient relief.

3. A gradual filling up of troughs with Tortonian deposits, up to the level of the Narayev unit, decreased the relative elevation

differences and locally partly obliterated the relief.

4. Some of the post-Cretaceous erosional highs of the buried surface persisted into Narayev time. They are reflected in gravel beds locally present in depressions, and in the cross-bedded layers of coarse algal nodular deposits along the highland slopes, such as in the Demnevka locality, in the area of Nikolayev.

4. These highlands, submerged in the Narayev sea, created shallow conditions favorable for red algae, i.e., intense daylight, the absence of terrigenous material deposited in troughs, aerated and mobile water, etc. This encouraged the growth of algae and intensified the deposition of lime. This is why the limestone thickness on these high banks is 2 to 3 times greater than normal for this widely-distributed unit.

SUMMARY

In the Paleogene of the Crimea and Eastern Carpathians, lithologic units with shallow littoral nodules of red algae are associated with glauconitic rocks, pebble beds, conglomerate, cross-bedding and sedimentary breaks. The association of red algae with sea transgressions is best seen in the Neogene of the western Ukraine. Thus, red algae of the Oncophora beds are related to the maximum Helvetian transgression.

In the Baranovsk beds, red algae are associated with the lower transgressive part of the Lower Tortonian sedimentary sequence, and are lacking in its upper part. The change of the gypsum-anhydrite formation to limestone, clay, sand and sandstone of the Ratynsk formation introduces a new Late Tortonian transgression, with Upper Tortonian deposits of the Cis-Carpathian downwarp and southwestern rim of the Russian Platform forming a clean-cut sedimentary group. Red algae are developed only in the lower part of this group, their wide distribution coinciding with the maximum Upper Tortonian transgression, at the time of deposition of the Tarnopol' beds. In both the Helvetian and Tortonian, red algae occupied only the shallow platform zone of the basin. This connection between their wide areal distribution and a major transgression, at which time they become principal rock-formers, is explained, we think, by the establishment of normal marine conditions, at the onset of such a transgression, and the curtailment of clastic material as a result of submergence of adjacent land.

Thus, a wide distribution of red algae corresponds to definite stages in the basin development. This makes it possible at times to separate algal sequences as individual stratigraphic units, mostly of a local character (Narayev and Tarnopol' beds).

The association of red algae with sea transgressions (as well as with similar occurrences of glauconite) is very significant. In some instances the appearance of limestone carrying red algae nodules, or of isolated Lithothamnium nodules in conglomerate or gravel, may be interpreted as an evidence of a transgression (the Pokutsk beds of the Eastern Carpathian Paleogene), in one area; and may correspond to a sedimentary break in an adjacent area.

These premises do not always hold true. Thus, the wide distribution of red algae in the middle part of the Lower Tortonian (Opol'sk and Narayev beds) is connected with prolonged shallow conditions and a favorable paleogeography (small influx of terrigenous material). On the other hand, small nodules of dendritic red algae in the Lower Eocene of Lysaya Mountain, near Feodosiya, mark an incipient shallowing.

The following principal algal facies are present in the Ukrainian Tertiary: 1) littoral facies with coarse nodules, associated with a transgression or a regression; 2) littoral facies with small nodules and a considerable amount of terrigenous material (pebbles, gravel, sand); 3) coarse nodules and lumps in detrital algal limestone on long-enduring distant shoals and banks; 4) comparatively deep (up to 150 m) algal banks with dendritic nodules and a large amount of terrigenous arenaceous, argillaceous, or carbonate material; 5) bioherms of reef massifs (Upper Tortonian, also Sarmatian of Moldavia).

The first two facies belong to the shallowest water. The bioherm facies, too, may be shallow, but they lie farther away from shores and are made up chiefly of bark-carrying and dendritic forms, and rarely of algal nodules. The third nodular facies formed on open shoals also is located away from shores, as a rule, forming flat banks of rapidly accumulating nodules, usually with a fringe of detrital limestone. These banks existed during the Early Tortonian, in the confines of Podol'sk strait; and occur in the Upper Tortonian, east of Medbor. Relatively deeper banks (50 to 100 m) during the Early Tortonian (Opol'sk beds) were located in depressed bottom areas, associated with ancient erosional lows; during the Late Tortonian (Tarnopol' beds), they formed a wide belt west of the reef zone. During the Lower Eocene of the Feodosiya area, they appear to be associated with an even deeper, although shallowing, sea.

Thus, taken by themselves, calcareous

red algae are not related to microfacies variations. The conditions of their development are determined by other factors, apparently different for different species, inasmuch as the wide range (from 0 to 150 m) of depths at which these plants thrive corresponds to a number of facies of a normal marine environment.

This review of the distribution of calcareous red algae suggests a wide development of a shallow Tortonian sea of normal salinity, in the platform segment of the Ukraine, and the presence of broad lateral, less commonly elongated, shoals on elevated flat parts of the sea bottom, at some distance from the shore. These shoals are structurally connected either with the sea boundaries as fixed by the tectonic movements of the platform, or else with the ancient erosional bottom relief.

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BRIEF COMMUNICATIONS

QUARTZITE XENOLITHS AND THE SELECTIVITY OF GRANITIZATION IN THE SOUTHWESTERN ALDAN CRYSTALLINE MASSIF

by

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The voluminous literature on granitization contains occasional references to the selectivity and unevenness in the granitization of various rocks, as well as to the difficulties connected with granitization of quartzite. H. Read [10], while emphasizing that such rocks as quartzite often behave as "barriers" to granitization, states that they do so for purely chemical reasons. Noting the poor state of knowledge of granitization of quartzite and sandstone, N.G. Sudovikov states that "quartzite is strongly resistant to granitization . . . it often persists as isolated beds in strongly altered rocks" [7].

While concurring with this statement of fact by N.G. Sudovikov, it must also be noted in the interest of further clarification of the problem, that passivity, a relative chemical inertia, rather than "resistance" of quartzite occurs in the complex process of granitization of the most ancient Aldan rocks.

Strongly metamorphosed upper Archean rocks, assigned to the Iyengrien series by D.S. Korzhinskiy [3], are well developed in the southwestern part of the Aldan crystalline massif. Some 1,500 meters of quartzite lie at the base of this series whose overall apparent thickness in that area is estimated at 15,000 meters. The remaining - and the larger - part of the series is made up chiefly of crystalline schist of varied mineral composition. The observed varieties consist mostly of plagioclase, amphibole, pyroxene with subordinated biotite, quartz and potash feldspar, and small amounts of assorted accessory minerals.

A majority of the crystalline schists are characterized by a high content of K, Fe, and Mg, and by a comparative deficiency in SiO_2, which brings them close to basic rocks.

Despite the fact that quartzites are subordinate to crystalline schists in the composite Iyengrian section, where they account for about 20% of the total thickness, they are closer in their geologic position to the upper Archean granitoid gneiss than to crystalline schist. It should be noted here that the difficulty of a detailed stratigraphic study of the Iyengrian series is due to its facies inconsistency and especially to the extensive development of large granitoid gneiss blocks, which prevent a continuous correlation of the section.

The Archean exposures in the subject area amount to about 8,300 km^2, including about 6,200 km^2 of granitoid gneiss and migmatite (74.7%); 1,300 km^2 of quartzite (15.7%); and only 800 km^2 of crystalline schist or 9.6% of the Archean outcrop area.

The Iyengrian rocks outcrop among granitoid gneisses in greatly elongated isolated bodies of various sizes, from a few meters to tens of kilometers in length. With reference to granitoid gneiss, the first may be arbitrarily called micro-xenoliths; the second, macro-xenoliths. The direction of their elongation is in accordance with the general structural plan of the deformation and coincides with the strike of individual stratigraphic units, sequences and formations of the Iyengrian series. The general structural trend and the elongation of xenoliths is northwest.

Micro-xenoliths are remnants of larger structures, standing out in "islands" of Iyengrian rocks among the granitoid gneisses. They form extended sub-parallel outcrops, several kilometers wide, and traceable at times as far as 50 km along their trend. A number of such exposures are present in the upper course of the Aldan, in the basins of Yapoga, Amedichi, Ungra, and other localities. Here belong the Verkhnealdansk, Amedichsk and Ayannakhsk macro-xenoliths, all forming an immense structural arch at the northwestern centroclinal terminus of the major Aldano-Ungra syncline. The inner parts of this structure, made up of crystalline schist, are also granitized to a considerable extent (Fig. 1).

Among other major, essentially quartzite xenoliths are the Yagorinsk, Sontiitsk, and Khrustal'nyy. A group of smaller quartzite xenoliths is located in the Kuskandra basin

where they lie in isolated, structurally elongated to NW, bodies among granitoid gneisses, occupying a total of about 80 km^2. Here they represent the remains of a quartzite unit, left intact in the granitization of the upper Iyengrian series. As a possible structural extension of the Yagorinsk macro-xenolith in the middle Chuga basin, there are several quartzite xenoliths, locally with distinct narrow fringes of migmatized crystalline schist.

Although many macro-xenoliths are complex lithologically, they have quartzite for their main component accounting for 65 to 100% of the exposed area of individual, large xenoliths. For this very reason, and in the absence of well-defined stratigraphic contacts with other Iyengrian rocks, some of the early students of the Aldan geology erroneously associated the isolated exposures of strongly metamorphosed, massive crystalline quartzite among the granitoid gneisses (Belyye Mountains, western Yangi, the Khrustal' Mountain area, and other areas with the products of differentiation of a granite magma [2], aplite-quartzite, quartzite, and ultra-acid rocks of northfieldite or arizonite type.

In contrast to coarse quartzite xenoliths, crystalline schist occurs usually in smaller micro-xenolithic bodies, generally too small for the scale of an index geologic map. As a rule, they carry no quartzite.

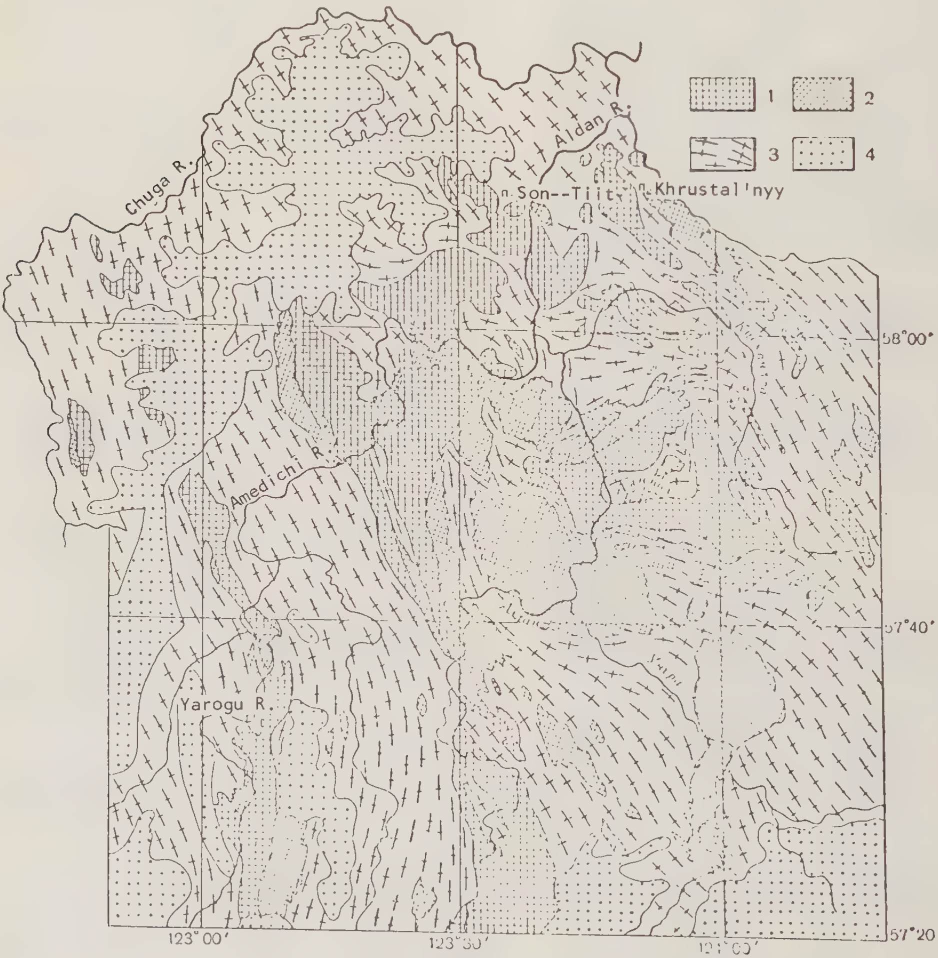

FIGURE 1. Exposure of quartzite and crystalline schist with relation to the upper Archean granitoid gneiss in the southwestern part of the Aldan crystalline massif.

1 -- quartzites of the Iyengrien series; 2 -- granitized crystalline schist; 3 -- upper Archean granitoid gneiss; 4 -- Proterozoic, Cambrian and Jurassic deposits.

Another characteristic feature of crystalline schist micro-xenoliths is their grouping in diversified series of different stages of granitization, isolated among the granitoid gneisses. Locally they are so closely intermingled with the granitoid gneisses as to form entire migmatic fields, fringes and strongly elongated zones trending with the Iyengrian rocks and often joined parallel with large quartzite xenoliths. The most extensive migmatic fields usually gravitate toward crystalline schist rather than to quartzite, as for example in the Aldan and Ungra basin, within the Aldano-Ungra syncline. In a number of places (upper reaches of Chuga, Amedichi and other rivers) crystalline schists show traces of a deep K-metasomatism in the form of feldspathized segments of a porphyritic structure, with large xenocrystals of feldspar producing an "augen" structure.

Large areas separating individual, large xenoliths are made up of granitoid gneiss which form the inherited stratified flat bodies, trending with the Iyengrian rocks and subordinate to the overall folded structure. The longer granitoid gneiss massifs can be traced for many tens of kilometers, along large structures, with tearing intrusive contacts conspicuously absent.

The relationship between the granitoid gneiss and the Iyengrian rocks, especially the crystalline schist, is very characteristic, being determined by a peculiar granitization, anisotropic in two directions -- with the strike and across it. Where typical, jagged contacts occur along the strike of the crystalline schist, with gradual changes and wedge-outs of facies-type transitions, the relationship across the strike is expressed in numerous alternations of crystalline schist and granitoid gneiss, with the formation of typical band structure migmatite. These latter contacts point to certain limits of granitization of crystalline schist.

The relationship between the granitoid gneiss and quartzite is altogether different, usually being expressed in much simpler contacts, without particular complications. Only locally, as in the Amedichi valley, are there areas of more complicated contacts expressed in an alternation of granitoid gneiss and bedded quartzite with intercalations of cordierite gneiss and crystalline schist, both affected by the granitization process.

The peripheral parts of the granitoid gneiss massifs have a mixed, contaminated composition, locally with more or less abundant, parallel bands of dark-colored minerals typical of the enclosing rocks. Their interior parts, however, are much more homogeneous, approching common granite in composition. It is most probable, therefore, that, as a result of intensified tectonic activity, a further rise of infiltrating, granitizing solutions took place after the formation of inner, deeper and more homogeneous segments of the granitoid gneiss massifs. This, in turn, leads to the belief that granitization proceeded by way of differentiation, along the lines of D.S. Korzhinskiy's principle of an infiltrational metasomatic column with magmatic replacement in its deeper parts [5].

The conformable banded texture of many granitoid gneiss varities, usually distinct near the xenolith contacts, becomes less so away from them, where it is almost massive or granoblastic, and the overall mineral composition more leucocratic. In such places, the definite connection with the emplacing rocks is lost, with a petrographic study generally ineffective in restoring it. Therefore each segment with a distinct residual banding becomes particularly interesting, inasmuch as this phenomenon means an excess of dark minerals inherited from the enclosing rocks and scattered unevenly in granitoid gneiss. This, together with micro-xenoliths found deep in the granitoid gneiss massifs, is a good indicator of the granitized volume of the crystalline schist.

It is significant that quartzites account for only 1/5 of the thickness of the Iyengrian series, while they take up over 2/3 of the overall xenolith area. Such a great difference in the ratios (by the factor of about three) in favor of quartzite, suggests that the granitization of the Iyengrian series proceeded chiefly at the expense of crystalline schist. The leading part played by quartzite in the composition of the xenoliths suggests that granitization (feldspathization) of quartzite is not as widespread as believed by some investigators.

Without rejecting feldspathization as a K-metasomatism, its intensity in nearly monomineral quartzite is open to doubt. It is utterly incomprehensible, why and how these rocks, above all, could accumulate feldspar. It appears that the investigation of the role of feldspars in quartzite is open to two lines of attack. It should be kept in mind that besides the infiltrational magmatic feldspathization of quartzite, locally demonstrable at direct contacts with granite, there are authigenic feldspars which underwent intensive cumulative recrystallization in an advanced process of metamorphism of quartz-feldspathic sandstone.

If Daly is right in saying that "quartz and feldspar of heated crustal rocks are in a quasi-eutectic relationship and are capable of dissolving and liquefying each other" [1], it is difficult to explain on the basis of

prevailing anatexis the preferential preservation of both primarily feldspathic and feldspathized quartzite while large blocks of other Iyengrian rocks disappear. Therefore, in rejecting this theory, it is more correct to assume the chemical (infiltration-metasomatic granitization) rather than the physical (anatexis) aspect of this phenomenon, in this region.

Only isolated small areas of quartzite were locally liquefied, to a certain extent, with the formation of characteristic rocks first recognized in the Aldan by Ye. M. Laz'ko, as a special formation of quartz anatecite [6]. However, that author's assumption of "a considerable development of granite, originating in remelting and selective fusing of crystalline rocks," along with the later view of N.G. Sudovikov that "granitization phenomena . . . take place under the conditions of selective fusing," [8] are not quite convincing in the light of the above discussion.

Keeping in mind Read's idea of the importance of chemical factors in granitization, we cannot agree with N.G. Sudovikov's view on the exclusive part selective fusing (anatexis) plays in the granitization process. He maintains that "rocks with a comparatively high resistance to granitization, include first of all basic and carbonate rocks, along with quartzite" [9] while arriving at the opposite conclusion that "the alaskite character of granite is determined by their origin . . . from feldspathized quartzite and leucocratic gneiss whose main feature was their repeated fusing" [9]. The factual material cited here shows, on the contrary, that near-basic rocks, namely crystalline schist, possess a much lower "resistance" to granitization than the quartzite.

The preservation of quartzite is to be explained not by their "refractory" properties (as against the "fusibility" of crystalline schist) but rather by the preponderance of granitization over anatexis. The problem of large quartzite blocks, preserved among migmatites and granitoid gneisses, is unequivocally solved by the assumption of a selective, essentially metasomatic granitization as the predominant petrologic process.

As a result of this process, the vast areas of the southwestern Aldan crystalline massif exhibit a definite selective granitization of rocks differing in overall chemical composition and other properties. In this respect, two main rock groups may be designated: essentially acid (quartzite) and near-basic (crystalline schist).

Considering the difference in the properties of these two groups of enclosing rocks, the formation of large granitoid gneiss blocks took place under greatly different chemical, physico-chemical and structural conditions. Of no small importance were the textural features, such as bedding or the lack of it, also the competence of rocks and their plasticity in the granitization zone. It is possible that the character and extent of granitization were affected by the plastic state of probably insufficiently metamorphosed rocks which underwent profound changes in the granitization zone.

Chemically more active crystalline schist consisting of a number of mineral substances unstable in the process of deep metamorphism were affected by granitization processes to a greater extent that the quartzite, consisting chiefly of chemically less active silica with an admixture of feldspars and certain other minerals.

In so far as the silica in quartzite was an "inert surplus component" in the process of replacement under the conditions of an acid granitization front, active replacement processes took place where quartz - according to D.S. Korzhinskiy - became a quite mobile surplus mineral in a definite metasomatic facies [5]. This precludes the development of perceptible processes of granitization in nearly monomineral quartzite, brought about by chemical replacement. It follows that granitization of quartzite could have been effected solely by an influx of "precipitated" minerals, namely feldspars, separated out of ascending infiltration solutions. In assuming an essentially metasomatic granitization for the Iyengrian rocks, it should be emphasized that the monomineral aspect of quartzite was utterly ineffective in promoting this process. According to D.S. Korzhinskiy, "the number of simultaneously stable minerals in a rock originating in intense metasomatism, unavoidably decreases, up to the formation of monomineral rocks" [4].

By definition, granitization is a directional process terminating in the formation of granitic rocks. Perhaps this is the reason for preservation of quartzite as even more acid rocks than granite. Since granitization of quartzite requires a lowering of their "super-high" acidity, this process - the opposite to granitization - probably cannot take place with nearly monomineral quartzite, without a sizable influx of other material.

In so far as granitization may take place through the influx of granitizing substances (K, Na, Si, etc.), besides the chemical resources of the rock itself, the presence of isolated quartzite in granitoid gneiss is a good proof of the difficulty of their change to granite, even with an excess influx of these substances (especially Si).

Granitization being a complex infiltration-metasomatic process of both chemical replacement and direct deposition of excess minerals, it is manifested more intensely in heterogeneous stratigraphic units and in sequences of monomineral, crystalline schists. Granitization of quartzite, on the other hand, limited chiefly to feldspathization, was less intense, and occurred only along comparatively narrow contacts. Consequently, while crystalline schists were almost fully granitized, the thickest sequences of quartzite remained nearly intact within their stratigraphic confines. Their exposures form a peculiar structural quartzitic "framework" - a result of a selective granitization of the Iyengrian rocks which formerly had a continuous lateral distribution.

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PETROGRAPHIC FEATURES OF INTRUSIVE MASSIFS OF THE SOUTH CENTRAL CRIMEA, IN THE LIGHT OF NEW DATA

by

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Intrusive massifs within the Crimean mega-anticline are "minor intrusions" related to extrusive complexes which are formed at early stages of geosynclinal development. Petrographically, they are rather little known, although the stratigraphy and tectonics of the mega-anticline are known in much more detail, thanks to the efforts of many geologists including M.V. Muratov [4].

The enclosing Tavrian Flysch series is Upper Triassic Rhaetian or Lower Jurassic, depending on the locality. It is folded into comparatively large flexures, trending NE, with both wings dipping NW and complicated by overthrusts and minor folding (Fig. 1).

According to our data, these intrusive massifs represent the enlarged upper parts of vertical dikes formed under near-surface conditions. They trend chiefly NE and NW, and they are sharply discordant with the enclosing Tavrian rocks [5].

Quartz diorite is mentioned in the

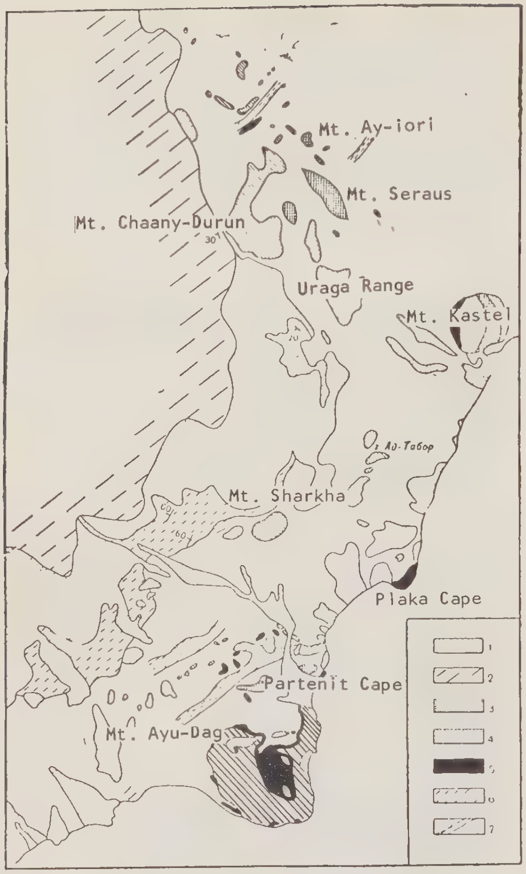

FIGURE 1. Geologic map of the south-central Crimea. Compiled by S.M. Kravchenko, 1956.

1 -- Upper Tertiary-Quaternary marine and alluvial deposits, landslides and creeps; 2 -- Lusitanian deposits, chiefly limestone; partly sandstone and conglomerate, in the north; 3 -- plagiogranite-porphyry, quartz-diorite-porphyry, occasional granophyre; 4 -- anorthite-biotite gabbro, quartz anorthite-biotite diorite and gabbro; diorites enriched in epimagmatic quartz; 5 -- porphyritic analogues of anorthite-biotite gabbro, quartz anorthite-biotite diorite and other coarse-crystalline rocks with an amygdaloid texture; 6 -- Middle Jurassic sandstone and argillite; 7 -- Tavrian series (Upper Triassic - Lower Jurassic); arenaceous argillaceous Flysch containing a markedly argillaceous sequence.

literature as the main component of the intrusive Crimean massifs [2, 3, 5]. Recently assigned to the same group are granodiorite, banatite and adamellite [3]. More acid intrusives are observed in the same region: they are erroneously called keratophyres, quartz porphyries, etc. [2, 3].

As a result of the 1954-1956 study of the south-central Crimean intrusive complex, the author recognized two groups of different ages, as derivatives of two intrusive stages: a) widely distributed massifs of a predominantly basic composition and a complex structure; 2) younger acid massifs, homogeneously porphyritic with xenoliths of the first group (northeastern part of the Kastel' Mountain, Seraus Mountain, and other regions).

The basic intrusive massifs are made up of rocks differing in their structure: porphyries, porphyrites, evenly and coarsely crystalline. The porphyries make up the peripheral zone of the massifs, not over 15 meters thick, and having an amygdaloid texture.

Rocks differing in quartz content are recognized in the basic massifs. Thus, the content of principal minerals, plagioclase and monoclinic pyroxene, fluctuates here within a comparatively narrow range, while that of quartz ranges from 0 to more than 30%.

The major properties of the principal minerals remain constant in all rocks.

Plagioclase, as a rule, is zoned. The results of numerous measurements on the Fedorov table show that it corresponds to nos. 80-85, in the composition of central zones which usually account for 9/10 of the entire volume of the crystal, regardless of the amount of quartz in the rock and of the latter's structure. The plagioclase composition in the central zone varies within a range of 5 to 10 numbers; in the peripheral zones, it changes abruptly in the albite direction, attaining at times the composition of oligoclase and albite. The latter, judging by the character of its growth and the composition change from zone to zone, is of magmatic origin. The albite series is characterized by its twin triads and by a combination of twins in the second and third pinacoids (or in the rhombic section). Most plagioclase is apparently of a disorganized type. Monoclinic pyroxene also is often represented by zoned crystals. In the center, 2V usually is equal to 40°; c : γ = 38-40°; in peripheral part of a crystal, 2V increases to 60°, and c : γ to 44°. Quartz either fills up small interstices, practically not corroding the plagioclase (usually when its content is small), or else is found in a strongly corrosive relationship with the latter, in places forming micropegmatitic or granophyric growths. Titanimagnetite, rhombic pyroxene (often hypersthene) and olivine at times constitute the main rock-forming minerals. Among the associated minerals are: primary hornblende, biotite, magnetite, ilmenite, apatite, zircon, and anorthite. Observed among the secondary minerals are chlorite, uralite hornblende, iddingsite, actinolite, leucoxene, sphene, phrenite, epidote, carbonates, quartz, chalcedony and zeolites.

The main reason compelling many students of the Crimean intrusive massifs to assign certain rocks of the basic massifs to normal, intermediate and acid categories evidently was the presence of a large amount of quartz in many rocks. At the same time, basic rocks gradually changing to more acid (in chemical composition) were not fully identified, while micro-pegmatitic, typical corrosion structures (Fig. 2, b, d) were treated as magmatic structures [3]. An intense quartz corrosion of basic plagioclase in certain silica-rich rocks points to an epimagmatic origin of the bulk of the quartz. Interstitial quartz, on the other hand, evidently crystallized at a magmatic stage, as a result of rapid cooling, as was assumed by F. Barth for interstitial quartz of basalt [7]. In the latter case, quartz-free rocks with a more acid terminal composition of plagioclase could have been formed, with slow cooling and a balanced crystallization, since virtually quartz-free rocks occur even among biotitic and anorthitic varieties in the Ayu-Dag, Chamny-Burun and other massifs.

Under the conditions of a slow cooling and

FIGURE 2. Rocks of intrusive massifs. Photomicrographs.

a -- gabbro with an ophitic structure; b -- coarse-crystalline bytownitic rock, enriched with epimagmatic quartz; c -- metasomatic rock, greatly enriched with epimagmatic quartz and albitized (a veinlet); d -- contact between vein gabbro-porphyrite, probably containing glass at one time, and a coarse-crystalline gabbro.

Nicols crossed; magnification, 30X.

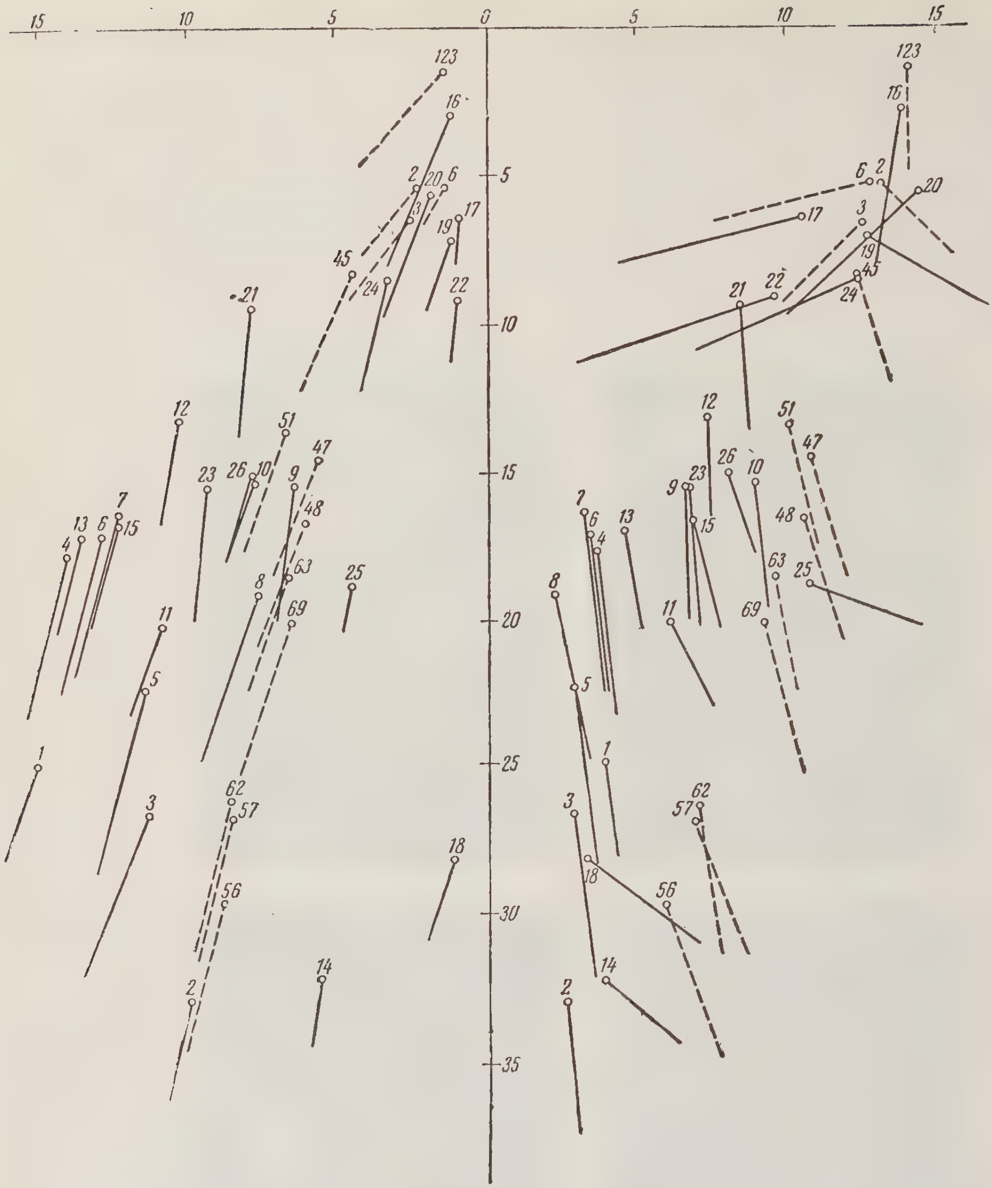

FIGURE 3. Chemical composition of rocks in the south central Crimean intrusive massifs. After V.A. Zavaritskiy.

Dashed vectors -- average compositions of rocks, after R. Daly: 2 -- Precambrian granite; 3 -- post-Cambrian granite; 6 -- liparite; 123 -- granite aplite; 45 -- granodiorite; 47 -- diorite (including quartz varieties); 48 -- quartz-free diorite; 51 -- hypersthene andesite; 56 -- olivine gabbro; 47 -- gabbros (total); 63 -- quartz gabbro; 69 -- quartz basalt; 62 -- olivine basalt.

Solid vectors -- rock compositions for south-central Crimea: 1 - 8 -- author's conversions of quantitative-mineral composition into chemical; 9 - 15, 18, 21, 23, 25, 26 -- chemical analyses [2, 6] of basic massifs rocks; 16, 17, 19, 20, 22, 24 -- chemical analyses [2, 6] of rocks from acid porphyritic massifs.

a balanced crystallization, the amount of silica tied up in plagioclase must be greater than under the conditions of rapid cooling. With the 60% plagioclase content in a rock, and of 9/10 of this amount corresponding to No. 80, this difference will reach 4.8% (taking into consideration the amount and composition of the acid fringe). This figure gives an idea of the amount of quartz which may be separated in rapid cooling. Where a larger amount of quartz is present and the structural relationship of the minerals pointing to a magmatic origin of quartz, the latter probably crystallized as a result of deep-seated assimilation of silica in the melting and reworking of the captured material.

According to F. Yu. Levinson-Lessing, quartz, titano-magnetite and olivine (very rare) gabbros with an ophitic structure (coarse-grained, 1 to 5 mm) and gabbro-diabases (Fig. 2 a) are present among the rocks making up the basic massifs, by their chemical ([3, 5, 6] Fig. 3) and quantitative mineral composition, as well as by the structural relationship between quartz and plagioclase. Among more acid rocks, carrying a considerable amount of quartz, hybrid rocks (hybrid gabbro-diorite and diorite) are recognized along with rocks altered by epimagmatic processes of adding silica (Fig. 2 b). Analogues of all of the above-named rock types with a diabasic texture of their ground mass are present among porphyritic near-contact rocks. All of the above-named varieties occur in places within the same massif and are connected by gradual transitions. The epimagmatic stage witnessed the albitization processes in individual zones and the formation of calcite and quartz veins with a poor sulfide mineralization (chalcopyrite, galena, sphalerite, etc.).

The younger acid rocks correspond to plagiogranite-porphyry and diorite porphyry in composition. The acid intrusive massifs are usually albitized, either fully or in part. In non-albitized rocks, the porphyritic separates are represented by quartz (usually predominating), zoned andesine Nos. 44-40, pyroxene, hornblende and biotite. The groundmass is most often microlitic, at times felsitic. Potash-feldspar is found only in the groundmass.

The results of study of the south-central Crimean intrusive rocks suggest, contrary to the opinion of previous investigators, that the original intrusive magma was of a basic composition, close to that of basalt magma. An essential part in the formation of derivatives at the first intrusive stage was played by fractional crystallization, by the assimilation of silica during movement of the molten mass, and by an influx of it at the epimagmatic stage. In the formation of the second stage derivatives, much smaller amounts of acid molten materials were injected, as a result of evolution of the common magmatic source in the direction of a general assimilation of acid material, at depth. These conclusions may be generalized to a considerable extent for other Crimean areas of intrusive massifs.

In comparing the spilite-keratophyre complexes of different areas, V.A. Zavaritskiy notes the unusually acid overall composition of the Crimean Kara-Dag spilite-keratophyre complex [1]. The obvious reason is that the initial batches of the most acid magma did not reach the surface in the Kara-Dag area. Instead, during cooling under hypabyssal conditions, they gave rise to massifs of bitovnite gabbro, hybrid rocks, and rocks altered by the apimagmatic processes of silica influx (fragments of such rocks are observed in the Kara-Dag conglomerate and tuffobreccias).

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FINDING OF OTOCERAS IN THE LOWER TRIASSIC OF THE EASTERN VERKHOYAN'YE REGION

by

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Lower Triassic ammonites of the genus Otoceras Griesbach have been known until recently only from the Himalayas and eastern Greenland, where they occur at the base of the Lower Triassic, directly above the Permian. The Otoceras beds are so peculiar in their ammonite fauna that Spath [7] found it possible to classify them in a special extended biostratigraphic Otoceratan zone, lying directly above Permian deposits.

Despite their biostratigraphic importance, otocerata have not been found anywhere, except for the two above-named areas and a doubtful finding reported by Welter from the island of Timor [9]. This renders their finding in the Lower Triassic of the eastern Verkhoyan'ye region ever so much more important. We are indebted for it to the Dal'stroy geologists, S.V. Domokhotov and V.I. Konovtsev. The new locality connects the Himalaya and Greenland regions, suggesting a probable path of Otoceras migration from the Pacific basin into the boreal zoogeographic province by way of a Verkhoyansk geosynclinal sea.

LOWER TRIASSIC DEPOSITS OF THE EASTERN VERKHOYAN'YE REGION

Lower Triassic otocerats were collected in 1955 by S.V. Dobrokhotov and V.I. Konevtsev on spurs of the high Suntar-Khayata range, some of whose peaks stand above 3,500 m. The location is in the headwaters of Suntara River, a left tributary of the Indigirka, in exposures along Ugamyt and Kerekhtyakh streams.

According to Domokhotov, Lower Triassic rocks are underlain there by the Imtachansk formation of greenish-gray sandstone and siltstone rhythmically alternating with black shale, and having an overall thickness of 700 to 800 m. Its Permian age is determined by a peculiar fauna of numerous large pelecypods, Kolymia pterinaeformis Popow, K. inoceramiformis Licharew; gastropods, Bellerophon (Warthia) imtatschanensis sp. nov. (Popow in coll.), Pleurotomaria aff. nuda Dana, Pl. cf. yabeshigerui Kob.

The Imtachansk formation is well defined by its numerous bellerophontids, which affords an easy recognition of the Permian-Lower Triassic boundary, in the field. The Bellerophon horizon, directly underlying the eastern Verkhoyan'ye Lower Triassic, brings together the Verkhoyansk section and that of north China where the lobin formation locally changes to Bellerophon carrying sandstone and shale [1]. The Varkha Bellerophon beds occur in the Solyanoy ridge [10]; an Upper Permian Bellerophon limestone is also known from the eastern Alps.

The Imtachansk formation is apparently conformably overlain by dark-gray pelitic shale with cherty lime concretions and a fauna of Lower Triassic otocerats: Otoceras boreale Spath, O. indigirense Popow sp. n., also Anodontophora borealis Spath, which define the lowermost Triassic Otoceratan zone (after Spath, [7]). In the Tyra basin, these shales barely reach 15 m and are replaced by sandstone.

The Otoceras shales are overlain by the multi-colored Nekuchansk formation of alternating siltstone, sandstone and shale, colored gray, green, red and brown. Ammonites, present in this formation, are typical of higher Lower Triassic horizons: Hendenstroemia mojsisovicsi Dien., Clypeoceras gantmani Kipar., Paranorites sp., and other forms identifying the Gyronitan and Flemingitan zones of the Lower Triassic Ind stage.

Above the Nekuchansk formation lies the Kharchaysk formation carrying Estheria (Olenek stage?), sandstone with remains of a (Middle Triassic?) flora and the Dalankichansk formation of conglomerate, sandstone and shale with Halobia zitteli Lindst. and other Upper Triassic pelecypods.

DESCRIPTION OF GENERA

Family Otoceratidae Hyatt [5].

Description: shell involute, with a deep umbe, usually with an umbonal shaft. Ventral side sharp or with three keels. Suture line with a wide median saddle, with later forms.

Note: Spath [6] includes in this family three Upper Permian genera, Prototoceras Spath (1; genotype Geratites trochoides Abich-2), Discotoceras Spath ([6]; genotype Hungarites raddei Arthaber-3), Anderssonoceras Grabau and Lower Triassic genera, Otoceras Griesbach [4] with subgenera Otoceras s. s., Metotoceras and Anotoceras Hyatt [5]. Metotoceras Spath (6; genotype Hungarites sp., ind. Diener, 1897) differs sharply by the absence of umbonal lobes and by the suture form. There are reasons for its recognition as a separate genus. In that case, the family will include only six genera and about 18 species.

Lower Triassic forms differ from the Permian in their larger size; they are megalomorphic descendants of smaller Upper Permian Forms.

Genus, Otoceras Griesbach [4].

Genotype, Otoceras woodwardi Griesbach ([4], p. 106. plate 3, fig. 4).

Description. Shell involute, with a very deep umbo and rapidly growing whorls. Near-umbonal parts of shell, on both sides, are strongly protruding in extended lobes with sharpened edges. Whorls subrhomboidal in cross-section (after Griesbach).

Distribution. Lower Triassic Ind stage, Otoceratan zone. The himalays, eastern Greenland, eastern Verkhoyan'ye region.

Note: in 1897, Diener separated four new genera in the Griesbach collection, in addition to the earlier two. Spath [8] identified two new forms in eastern Greenland. Among forms collected in the eastern Verkhoyan'ye Lower Triassic, there is Ortoceras boreale Spath and endemic forms united in a new genus O. indigirense Popow sp. n.

Genus Otoceras Spath [8] (Fig. 2, 1a, b).

Description. Shell with three keels on ventral side, with elongated umbonal lobes. Suture line with depressions in secondary saddles.

It differs from O. droupadi Dien. by its wider umbo; from O. fissisellatum Dien., by a thinner shell.

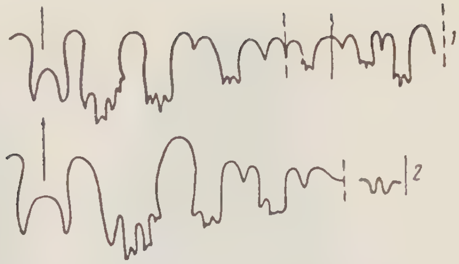

FIGURE 1. Suture lines of Otoceratidae. Lower Triassic, Ind stage; eastern Verkhoyan'ye region; Kerekhtyakh brook.

1 -- Otoceras indigirense Popow sp. n. (2/3 natural size); 2 -- Otoceras boreale Spath (1/3 natural size).

	Shell dimensions			
Otoceras boreale Spath (6, holotype, pl. 1, fig. 1)	73	53	37	14
Verkhoyansk specimen no. 38/6399	145	55	42	14(?)

(First column, shell diameter in millimeters; second, third and fourth columns, ratio of height, thickness and diameter of umbo, respectively, to the shell diameter, in %).

Shell has a narrow ventral side with three keels. The middle keel is high and sharp. Lateral sides smooth, spreading apart toward the umbonal edge. Umbonal edge abrupt and sharp, forming umbonal lobes. Umbonal side elevated, sloping at an angle with the umbonal suture. Growth lines form a poorly defined sinus on lateral sides and a protrusion toward the mouth, on ventral side. Whorl subtrapezoid in cross-section.

Suture line (Fig. 1, 2) ceratitic, consisting in its external part of a divided ventral lobe, two lateral and three auxiliary lobes. There are characteristic inflections in the apices of the second lateral and first auxiliary saddles (heteropolar inflection type).

In its size and form, as well in the structure of its suture line, the Verkhoyansk form is akin to the east Greenland form. It differs from Otoceras indigirense sp. n. in its flatter umbonal side and in the three auxiliary suture lobes. It differs from the Himalayan species by its thinner shell and by the umbo dimensions.

Distribution. Ind stage of the Lower Triassic; Otoceratan zone, eastern Greenland, eastern Verkhoyan'ye region.

Locality. Eastern Verkhoyan'ye region,

FIGURE 2

1 -- Otoceras boreale Spath: a -- side view; b -- central view (1/2 natural size)

2 -- Otoceras indigirense Popow sp. n.: a -- side view; b -- ventral view (1/5 natural size).

Suntar-Khayata range, Ugamyt brook, a left tributary of the Suntara, Indigirka basin, exposure 1757; collection of V.I. Konevtsev, 1955; no. 38/6399, F.N. Chernyshevskiy Geological Museum, Leningrad.

Genus Otoceras indigirense Popow sp. n. (Fig. 2 a, b).

Description. Shell similar to O. boreale but thicker, with a perfectly vertical umbonal side and poorly expressed umbonal lobes.

Shell dimensions

125	53	45	16
155	56	53	16

The vertical umbonal side and the resulting decrease in height of umbonal lobes clearly distinguishes the Verkhoyansk form from the Greenlandian and Otoceras boreale Spath. Its other feature is the lack of one umbonal lobe in the outer part of the suture (Fig. 1, [1]).

Distribution and locality. Ind stage of the Lower Triassic. Eastern Verkhoyan'ye region, Ugamyt, Kerkhtyakh brooks, tributaries of the Suntara. Indigirka basin; collection of V.I. Konevtsev, 1955; exposure 1757, two specimens together with O. boreale; and two specimens in exposure no. 2034.

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EVIDENCE OF PERMAFROST PROCESSES IN QUATERNARY DEPOSITS OF THE NORTHERN CASPIAN REGION

by

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A study of rock deformations originating in connection with freezing is of importance in correlation of periglacial and glacial deposits.

Only isolated references to such disturbances are found in the literature on the Quaternary of the lower Volga region. Thus, M.M. Zhukov [2] notes in his description of an exposure at Yenotayevka that folds are observed in the Khazarian lacustrine clays which are not reflected in the adjacent beds. In describing Quaternary deposits in the area of paleontologic station Rynok (in the Sukhaya Mechetka ravine, on the northern edge of Stalingrad), A.I. Moskvitin points out that sandy sediments, assigned to the lower part of the Atel'sk (Pleistocene), penetrate the underlying rock in numerous wedge-like fractures. On the basis of data of M. N. Grishchenko - who studied in the village of Chernyy Yar the surface of the Atel'sk beds pierced by pseudomorphs of ice wedges filled up with the overlying sand - A.I. Moskvitin concludes that all of the Atel'sk beds were deposited during a period of permafrost action which reached as far as the Near-Caspian plain. Later on, M. N. Grishchenko and A. I. Koptev [1], working in the area of Privolzh'ye village (below Syzran'), observed pseudomorphs of ice wedges piercing the top of Atel'sk loams, affected by soil-processes and partially eroded. This virtually exhausts the data on permafrost deformations of the lower Volga Quaternary deposits.

During 1955 field work, the author succeeded in gathering new evidence of permafrost. Exposures in the Volga bank at Chernyy Yar revealed intense folding at the top of Khvalynsk chocolate-colored clay, with flexures up to one meter high, which were not repeated in the adjacent beds. Similar folds were observed in other Volga sections, e.g., at Vladimirovka (Yenotayevskaya) and below Lenino; and again in exposures along

the lower course of Ural, near settlements Mergenevskoye and Kolovertnoye; along the Bol'shoy Uzen', near Kharlamova; and along the Malyy Uzen', below Aleksandrov-Gay and near Lokhmotovka, where the top of chocolate-colored Khvalynsk clay is folded into small flexures (not over 0.5 m thick). Evidence of bulging is also present. This folding appears to be a result of solifluction of a plastic rock and possibly an effect of pack ice. There is no doubt that this deformation took place immediately after the deposition of the chocolate-colored clay, and before that of the Upper Khvalynsk beds.

Permafrost phenomena were observed lower in the section, as well. In the Chernyy Yar exposure, the top of Upper Khazarian (Atel'sk) lacustrine clay is broken by fractures filled up by sand from the overlying Khvalynsk bed; in the Kopanovka and Yenotayevka exposures, the top of the Atel'sk loams carries pseudomorphs of ice wedges, 2 m long and 0.2 to 0.3 m wide, also filled by the Khavlynsk sand with a mixed fauna. It is obvious that these wedges were formed after the Atel'sk loams were deposited, just before the Khvalynsk transgression.

The next stratigraphic unit associated with intense and numerous cryoturbations are the Atel'sk (upper Khazarian) beds. The Chernyy Yar exposures exhibit pseudomorphs of ice wedges filled up with sand which make up a lense in the Atel'sk loam. The base of the latter, at its contact with the Chernoyarskiy sand, is folded into flat flexures, with local bulging. In the nikol'skoye (lower Volga) outcrop, the lower part of the Atel'sk loam forms complex steep folds. Similar folding occurs at both the top and base of the Atel'sk unit, in the Kopanovka exposure. At the same locality, by the pier, the folding has affected an entire unit of loam and sand. Analogous phenomena are present in the Yenotayevka, Vladimirovka (Yenotayevskaya) and Grachi exposures. Small pseudomorphs of ice wedges in the Atel'sk lacustrine clay were noted on the Bol'shaya Uzen' river, below Aleksandrovka.

All of these instances corroborate A.I. Moskvitin's conclusion that the Atel'sk beds were formed during a period of permafrost activity.

The lowest stratigraphic unit with evidence of cryoturbation is the top of the lower Khazarian. In collaboration with A.I. Moskvitin, the author found an ice wedge pseudomorph, five kilometers below Aleksandrov-Gay, on the Bol'shaya Uzen'. It cuts the top of the lower Khazarian loam, affected by soil processes, eroded and changing downward to marine lower Khazarian deposits. These loams are overlain by sandy loam and loam of the Atal'sk (upper Khazarian) unit.

Thus, the evidence observed in the lower courses of Volga and Ural, as well as on the Malaya and Bol'shaya Uzens points to several phases of abrupt cooling which resulted in cyroturbations. These periods of cooling occurred: a) at the very beginning of late Khazarian time (the wedge pseudomorph in the top of the lower Khazarian) separated from the following cool period by a warm period at the time of deposition of the Chernoyarskiy sand; b) at the time of deposition of the Atel'sk loam; it is separated from the next cool time by a period of soil formation, followed by erosion; c) before the maximum Khvalynsk transgression (wedges in the top of the Atel'sk loam); d) at the close of middle Khvalynsk time (cryoturbations in the uppermost chocolate-colored clay).

It follows that the cryoturbations of the lower Volga and throughout the Northern Caspian region are the results of cool periods prevailing throughout the Russian plain, in the Quaternary.

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LOSSES OF SCIENCE

On May 9, 1958 STANISLAV ANTONOVICH BOROVIK, Doctor of Physical and Mathematical Sciences, Professor and a collaborator of long standing at the Institute of Geological Sciences of the Academy of Sciences of the U.S.S.R. passed away. He was born on March 1 (February 17) 1882, graduated from the Physical Mathematics Department of the Petersburg University (1907) and stayed on to give a course in physics. His early scientific work was dedicated to radioactivity of medicinal muds and air enclosed in soils. At the same time he proposed a number of technical improvements expediting detailed analysis of the composition of minerals.

From 1930 until his retirement in 1956, he directed the Spectrum Analysis Laboratory of the Academy of Sciences, where he developed methods of qualitative and quantitative spectrum analyses of rare and scattered elements. Of practical importance was his work on identification of germanium, niobium, tantalum, cesium, scandium and rare earth elements, in various rocks. He was the author of more than 80 scientific works in the field of methodology of spectrum analysis, geochemistry and physics.

S.A. Borovik was awarded the Orders of Lenin and the Workers' Red Banner.

On June 22, 1958 ALEKSEY NIKOLAYEVICH IVANOV, Doctor of Geologic and Mineralogic Sciences and Superintendent of the Stratigraphic and Paleontologic Laboratory at the Mining Geological Institute of the Uralian Affiliate of the Academy of Sciences passed away. He was born on February 21 (9) 1869. At the age of 17 he went to work in the Lun'yev coal mines, was promoted to mine surveyor and from then on devoted his time to geology of the western slope of the Urals, studying coal deposits, many of which he discovered.

Of considerable scientific interest are his works on the details of Devonian and Carboniferous stratigraphy, on the fauna of these deposits, the tectonic details of the Western Urals, and on the so-called "barren sequences." After 1917, A.N. Ivanov taught at Perm University; and after 1925, in the Sverdlovsk Mining Institute. For many years he was an associate of the Geological Committee and the Ural Geological Administration. A.N. Ivanov was awarded the Order of Lenin.

On July 26, 1958 Professor ALEKSANDR ALEKSANDROVICH GAPEYEV, Doctor of Geologo-Mineralogical Sciences, died; he was one of the greatest experts on the geology of the U.S.S.R. coal deposits. He was born August 19 (7) 1881, graduated from the Petersburg Mining Institute (1910), and then worked for the Geological Committee. In 1920 he became Professor and Director of the Ural Mining Institute, then was transferred to the Moscow Mining Academy and finally to the Moscow Mining Research Institute.

A.A. Gapeyev studied the largest coal regions of the U.S.S.R., such as the Donets and Kuznetsk basins; he worked in the Caucasus, Urals, Kazakhstan, Central Asia and Sakhalin. He was the first to show the industrial importance of the Karaganda basin and to identify indigeneous coke coal. For this work he was awarded the Stalin Prize, in 1948. He made important contributions to the classification of coals and to the methods of computation of their reserves. He published over a hundred scientific papers. In 1933, he was named Honored Scientist and Technician of the U.S.S.R.

A.A. Gapeyev was honored with the Order of Workers' Red Banner.

On July 28, 1958, Instructor in Paleontology ALEKSANDRA IL'INICHNA SHISHKINA-BOGACHEVA passed away. She was born April 1 (March 20), 1885, graduated from a private girls' school in Petersburg in 1910, and entered the Department of Natural Sciences of the Tiflis Institute for Women. In

1915, she became Assistant in Paleontology at the Khar'kov Institute for Women, then taught at the Don Polytechnic Institute, in Novocherkassk. In 1922 she became Assistant, and in 1930 Instructor in Paleontology at the Azerbaydzhan Polytechnic (subsequently Industrial) Institute. She directed her main efforts to the study of Neogene fossils. Of considerable scientific interest is her work on the fresh-water fauna of the Turkish Armenian salt deposits and on the Corbula beds of the Borzhom area.

On September 7, 1958 Professor NIKOLAY MIKHAYLOVICH SINITSIN, Doctor of Geologic and Mineralogic Sciences and a member of the Communist Party of the U.S.S.R. died tragically. He was born on April 26 (13), 1909 and graduated from the Leningrad Mining Institute in 1931. His scientific activity is connected with study of the Central Asian highlands. He participated in the making of geologic maps, the search for ores and in working out the problems of stratigraphy, tectonics and geomorphology of that region. He discovered several deposits of rare metals. Of great importance is his study of regularities in the lateral distribution of Central Asian mercury deposits.

His extensive teaching career began in 1931. In 1950 he took charge of the course in general geology, and in 1951 became Dean of the Geological Department of Leningrad University.

He was the author of over 50 scientific papers.

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REVIEWS AND DISCUSSIONS

PALEOTECTONIC MAPS. JURASSIC SYSTEM [1]

The appearance at the end of 1956 of the first issue of the Paleotectonic Atlas of the U. S. A., dealing with the Jurassic, soon after the 1952-1953 Soviet publication of the two-volume Atlas of lithologic facies maps of the Russian Platform (by the All-Union Scientific Research Geologic Exploration Institute, Geochemical Division) reveals the growing need for such publications. Besides their general scientific value in revealing basic principles of geologic development of large provinces, such atlases form a basis for predicting the distribution of various lithologic formations and associated useful minerals, particularly coal, oil, iron and manganese ores, bauxite, phosphate, etc.

Like the Russian Platform Atlas (Mesozoic), these maps are on a scale of 1:5,000,000, in nine sheets. Sheet I is an index of localities providing the data for lithologic facies and isopach maps. Sheet II is a paleogeologic map of the base of the Jurassic; Sheet III shows the total thickness of the Jurassic and the distribution of Jurassic intrusives; Sheets IV-VII are lithologic facies maps of stratigraphic subdivisions of the Jurassic, according to the authors. There are four such subdivisions: 1) "Interval A," corresponding to the Liassic, including the Toarcian; 2) "Interval B," embracing the Bajocian, Bathonian and Callovian series. (The authors do not recognize the Aalenian stage, apparently following W. J. Arkell's usage); 3) "Interval C," corresponding to the Oxfordian; and 4) "Interval D," which includes the Kimmeridgian and Portlandian. A correlation table shows the local stratigraphic units (groups and formations in the American nomenclature) included in a given interval, in different Jurassic regions of the U. S. A. (24 in all). The table discloses that the number of formations in these intervals varies from region to region, which naturally affects the precision of mapping.

Lithologic facies are designated according to W. Krumbein's method, in a quadrangle whose apices mark anhydrite and gypsum, limestone and dolomite, silt and clay, and finally sandstone. The sides of the quadrangle are divided into four intervals (Fig. 1). In this way, a quantitative representation of principal rock types is achieved. Rock types are represented by different colors (blue for limestone and dolomite, violet for anhydrite, brown for clay, yellow for sandstone). Volcanics and localities where they are missing within the general area of their distribution are marked with special symbols. Areas where deposits of a given age are not found by drilling, are regionally missing or not studied, are left blank. Isopachs are drawn at each 100-foot interval and are marked according to their authenticity. There are inserts showing cross-sections of lithologic facies drawn in the most revealing directions.

Jurassic deposits of the U. S. A. are distributed chiefly in the west, on the western part of the North American platform, in the Rockies and the Cordilleras. Beginning with the Upper Jurassic, they appear along the Gulf of Mexico. The maps give a fairly detailed picture of the distribution of lithologic facies and thicknesses for the platform regions and the Rockies, where the Jurassic is represented by normal sediments. As to the Cordilleras and the Pacific coast, the authors show only isolated spots, mainly of volcanic formations, and isolated points of thickness. Isopachs and lithologic facies boundaries are not drawn here.

Sheet VIII presents nine paleogeographic maps of the U. S. A. on a smaller scale and for narrower stratigraphic intervals. The following provinces are represented: 1) oceans and interior seas; 2) continental accumulations; and 3) erosion and missing sediments. Map 10 of the same sheet shows the boundaries of sedimentary basins for the Jurassic as a whole, along with an attempt at subdividing the land according to the character of its relief. Sheet IX, the last, presents detailed paleogeographic maps of individual regions, for shorter time intervals. The

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[1]Paleotectonic Maps. Jurassic system. Published by the U. S. Geological Survey. Washington. 1956. By Edwin D. Mc Kee, Steven S. Oriel, Vernon E. Swanson, Margorie E. Mc Lachlan, James C. Mc Lachlan, Keith B. Ketner, June Waterman Goldsmith, Ruth Young Bell, and Dolores J. Jameson. With a separate section on paleogeography by Ralph W. Imlay.

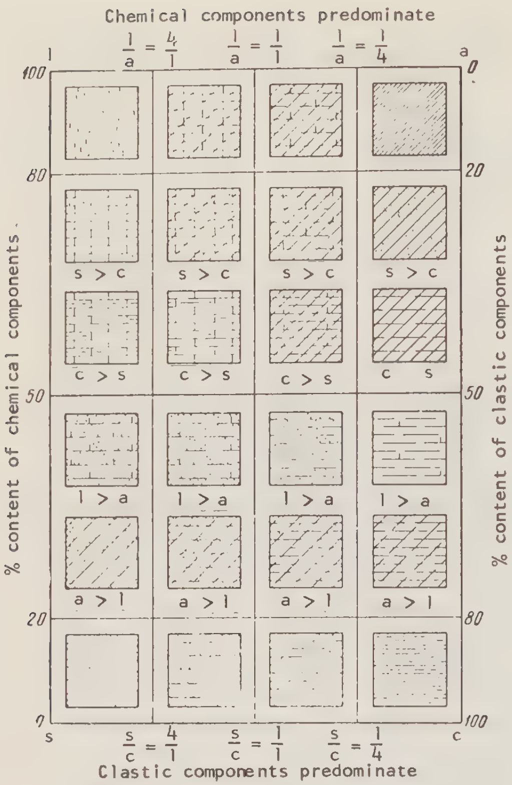

FIGURE 1. Legend to the lithologic facies.

a -- anhydrite and gypsum; c -- clay and sandstone; l -- limestone and dolomite; s -- sandstone.

paleogeographic differentiation is carried out in considerable detail, down to alluvial plains, peat bogs, lakes, deltas, saline lagoons, bars, dunes, seas with both normal and restricted circulation, littoral zones, etc.

The maps are preceded by an explanatory text including a data index and an extensive bibliography, with a roster of local stratigraphic subdivisions and intervals to which they are assigned on the maps, also a short legend for each sheet, explaining the method of map-making and evaluating the data. The legend ends with a summary of the tectonic conditions and development during the Jurassic.

The atlas undoubtedly is of great interest. Among its merits are: 1) an objective presentation of material data; 2) qualitative consideration of the relationship between main rock types; 3) a map showing the total thickness of the Jurassic system and a paleogeographic map of its base; 4) the explanatory text and the correlation table.

At the same time, we believe that the atlas has certain substantial shortcomings: 1) an arbitrary selection of stratigraphic intervals, as compared with the international scale, and inconsistency in their content which varies from region to region; 2) the difficulty in reading the complicated symbols for lithologic facies, and the absence of definite boundaries between the area of development of different facies: 3) the separation of lithologic facies maps from paleogeographic; 4) individual rock types, not fitting into the standard rectangle, cannot be shown on the maps.

In conclusion, we must note the great positive significance of this beginning of publication of an atlas of paleogeographic maps of the U.S.A. It is to be hoped that similar atlases for whole continents and for the entire world will be published on an international plan. The publication of such atlases will promote the recent trend from qualitative to quantitative geology. These atlases will be of great practical help. At the same time, they will facilitate the attack on a number of major theoretical problems of tectonics, historical geology, lithology and geochemistry.

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CHRONICLE

Preparatory work on the publication of geologic papers on the U.S.S.R. was begun in 1954 on the initiative of Academician V.A. Obruchev, supported by academicians N.M. Strakhov and K.I. Satpayev. The idea of initiating such work arose because numerous geologic publications, especially manuscripts, kept in various archives, are little known and inaccessible to a wide circle of geologists. As a result, they are very little used. This frequently leads to a repetition of previous investigation and to needless expense.

For the general administrative and scientific direction of all work, a commission on the state of geologic study of the U.S.S.R. (Academician N.S. Shatskiy, Chairman) was created by a resolution of the Presidium of the Academy of Sciences, U.S.S.R., in 1955. It included outstanding geologists from among the Academy associates, the Ministry of Geology and the Conservation of Mineral Resources, and several other departments. According to preliminary estimates, the task will amount to some 200,000 papers, annotations and bibliographic essays, reflecting material published since 1800, and manuscripts for the period after 1917. Besides the papers, a review chapter will be given on the development of different branches of geology for specific periods.

The realization of this plan began in 1956, in the geologic institutions of the Ministry of Geology and the Conservation of Mineral Resources of the U.S.S.R. and of the Academy of Sciences of the U.S.S.R. and the union republics' Academies. The Commission decided to divide the territory of the Soviet Union into regions coinciding as a rule with large administrative units. This generally agrees with the division accepted for the many volume Geology of the U.S.S.R., although the volume numbers of the two publications do not coincide.

Preparation of the volume, "State of Geologic Knowledge of the U.S.S.R.," for each region is conducted by a local editorial board.

A Commission conference with the participation of many local editorial boards was held in May, 1958, when final approval was given for the structure and form of the publication. Fifty volumes are under preparation, embracing the entire territory of the U.S.S.R. When the amount of material is large, the corresponding volumes will be divided into sections.

It was decided to abstract the most recent material; then, little by little, the earlier studies.

A single timetable was agreed upon: I, 1800-1860; II, 1861-1917; III, 1918-1928; IV, 1929-1940; V, 1941-1945; VI, 1946-1950; VII, 1951-1955. Such a timetable generally corresponds to the history of the economic development of the country.

Each book (volume or section) will contain four indexes: by authors, subjects, localities, and useful minerals and rocks.

Preparations for printing the issues containing the abstracts of all 1951-1955 publications and manuscripts dealing with the Latvian and Estonian S.S.R.'s, the Bashkirian S.S.R., and also of manuscripts on a large number of other regions, are being completed in 1958.

The most progress with the manuscript material is being accomplished by groups in the Armenian, Belorussian, Kazakh, Kirgiz, Tadzhik and Uzbek republics, also in the Volga-Don and Ural geologic administrations, the Volga Complex Geologic Prospecting Expedition, etc. The published material, however, is being abstracted here at an obviously slow rate.

A great organizational lag is noted in the Ukrainian and Moldavian S.S.R.'s. The work is also lagging in Siberia. For this vast region, however, there is already on hand Academician V.A. Obruchev's fundamental compilation, History of the Geological Study of Siberia, including publications up to and

including 1940. This lucky circumstance makes it possible to curtail the total volume of abstracting by concentrating only on bringing up to date the above review. However, in many geologic institutions, the working groups either have just started the task or else are carrying it out at an obviously inadequate rate.

The Conference has found that while manuscript abstracting by institutions of the Ministry of Geology proceeds satisfactorily in many regions, abstracting of publications and the compilation of review chapters lag. In many instances, the Academies of the union republics and the affiliated geologic institutes of the Academy of Sciences of the U. S. S. R. have not even started the work. This may hold up the publication of the volumes now in preparation.

It was noted by the Conference that the first compiled abstracts, alghouth not published as yet, have become a valuable reference material for a variety of geologic investigations, and are in great demand.

Considering the great interest in this work shown by the Academy of Sciences and the Ministry of Geology, it is to be expected that the publication of the State of Geological Knowledge in the U. S. S. R. will materialize. It will be of great help to geologists, geographers and economists, by providing the material necessary in planning and carrying out geologic investigations.

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